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14. ABSTRACT

This report on nanoscience terms highlights related Technical Reports and Research Summaries that are in the Defense Technical Information Center's collections. These terms are divided into six categories: nanomaterials, states and properties, nanometrology, manufacturing processes, quantum phenomena, and systems and devices. The terms were pulled from a broad scope of related fields in theoretical and applied sciences and describe past, present, and future applications.

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Atomic Force Microscopy

Introduction

The Atomic Force Microscope (AFM) was invented in 1986 by a pair of physicists to assist the "imaging, measuring, and manipulating" of nanoscale matter.[1] The AFM is a type of scanning force microscopy and uses a high-resolution scanning probe. The precursor to the AFM is the scanning tunneling microscope.

An AFM works by measuring the local property, such as height, with a probe placed as close to the sample as possible and then scanning an image of the sample. There are two types of scanning; contact, in which the probe touches the sample, and noncontact, in which the probe does not touch the sample. What is unique about the AFM is that samples can be scanned in air or submerged in liquid and the AFM does not use a lens; the size of the probe, rather than lens diffraction, determines the resolution of the resulting image.[2][3]

Atomic Force Microscopy Research

AFMs are used as laboratory tools in studies and experiments. Some of the research in which an AFM was used involved:

- Measuring surface elasticity [4]
- Defining optical characterization for potential applications in laser eye protection and anti-reflective coatings for high power laser optics [5]
- Understanding and developing improved control for nanoenergetic materials to be used as propellants and explosives [6]

The AFM Measures Topography with Force Probe

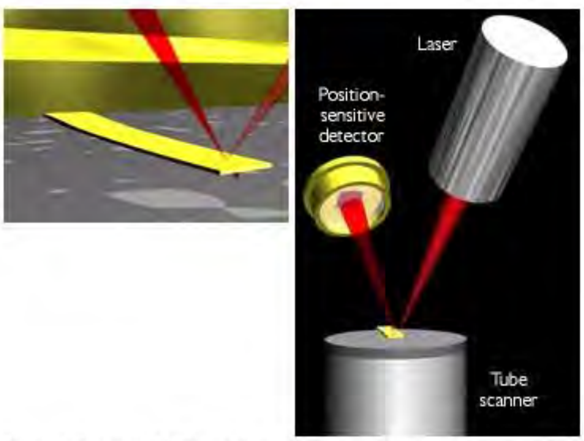

Figure 1. Concept of AFM and the optical lever: (left) a cantilever touching a sample; (right) the optical lever. Scale drawing; the tube scanner measures 24 mm in diameter, while the cantilever is 100 μm long.

From: Naval Research Laboratory
Image courtesy of the Naval Research Laboratory
http://www.nrl.navy.mil/chemistry/6170/6177/afm_concept.php

Footnotes

1. http://www.en.wikipedia.org/wiki/Atomic_force_microscope
2. http://www.nrl.navy.mil/nanoscience/AtomicForceMicroscope.php
3. http://www.nrl.navy.mil/chemistry/6170/6177/afm_concept.php
4. Goldberg, Jacob B., An Analytical Model of Nanometer Scale Viscoelastic Properties of Polymer Surfaces Measured Using an Atomic Force Microscope

5. Herr, Nicholas C., AFM-Patterned Thin-Film Photonic Crystal Analyzed by Complete Angle Scatter
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Goldberg, Jacob B., Air Force Institute of Technology, An Analytical Model of Nanometer Scale Viscoelastic Properties of Polymer Surfaces Measured Using an Atomic Force Microscope, March 2011, ADA539396, http://handle.dtic.mil/100.2/ADA539396.

Atomic Layer Deposition

Introduction

Atomic Layer Deposition (ALD) or Molecular Layer Deposition (MLD) "is a thin film deposition technique that is based on the sequential use of a gas phase chemical process." The process or ALD consists of four steps:

1) Exposure of the first precursor.
2) Purge or evacuation of the reaction chamber to remove the non-reacted precursors and the gaseous reaction by-products.
3) Exposure of the second precursor – or another treatment to activate the surface again for the reaction of the first precursor.
4) Purge or evacuation of the reaction chamber[1]

Atomic Layer Deposition Research

Steven George "review[s] several MLD systems that have been demonstrated to illustrate the current state-of-the-art.," also showing new systems "diversity of chemistries that can be employed to grow various hybrid organic-inorganic films." [2]

Minghwei Hong was the first to achieve "atomic-layer-deposited (ALD) oxides on GaAs and InGaAs and first to achieve inversion-channel GaN on MOSFET with ALD Al2O3 as gate dielectric." [3]

Footnotes

1. http://en.wikipedia.org/wiki/Atomic_layer_deposition
2. George, Steven M., Hybrid Organic-Inorganic Films Grown using Molecular Layer Deposition
3. Hong, Minghwei, High Dielectrics on High Carrier Mobility InGaAs Compound Semiconductors and GaN- Growth, Interfacial Structural Studies, and Surface Fermi Level Unpinning

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Hong, Minghwei, National Tsing Hua Univ Hsinchu, High Dielectrics on High Carrier Mobility InGaAs Compound Semiconductors and GaN - Growth, Interfacial Structural Studies, and Surface Fermi Level Unpinning, 19 February 2010, ADA514454, http://handle.dtic.mil/100.2/ADA514454.

Atomistic Simulation

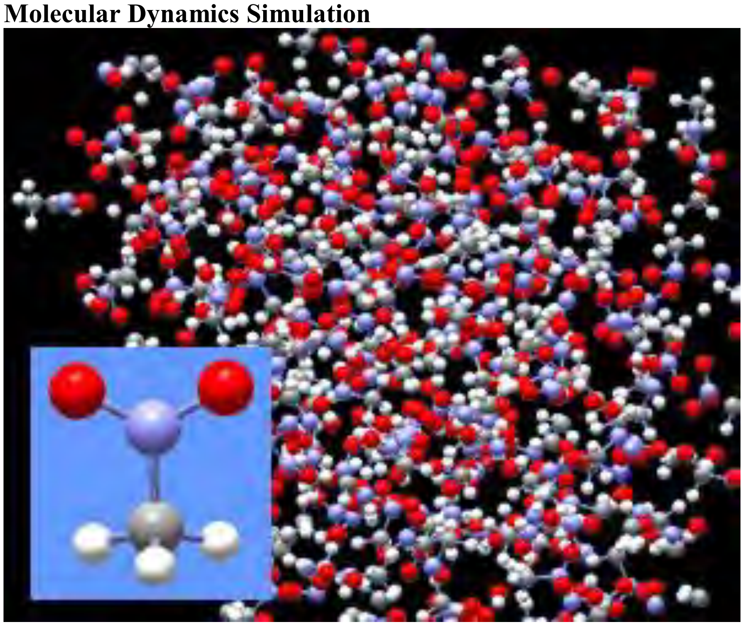
Introduction

Molecular Dynamics and ab initio are both examples of commonly used simulation approaches.[1][2]

Atomistic Simulation Research

An atomistic simulation was made to study diamond and graphite. The study found "that the simulation correctly reproduces experimentally determined trends in load versus penetration data." [3]

Molecular Dynamics Simulation



From: http://www.arl.hpc.mil/Publications/eLink_Spring07/user1.html
Image courtesy of the U.S. Army Research Laboratory, DoD Supercomputing Resource Center

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3. Harrison, J. A. et al., Atomistic Simulation of the Nanoindentation of Diamond and Graphite Surfaces

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Harrison, J. A.; Colton, R. J.; White, C. T.; and Brenner, D. W., Naval Research Laboratory, Atomistic Simulation of the Nanoindentation of Diamond and Graphite Surfaces, April 1992, ADA249296, http://handle.dtic.mil/100.2/ADA249296.

Biomineralization

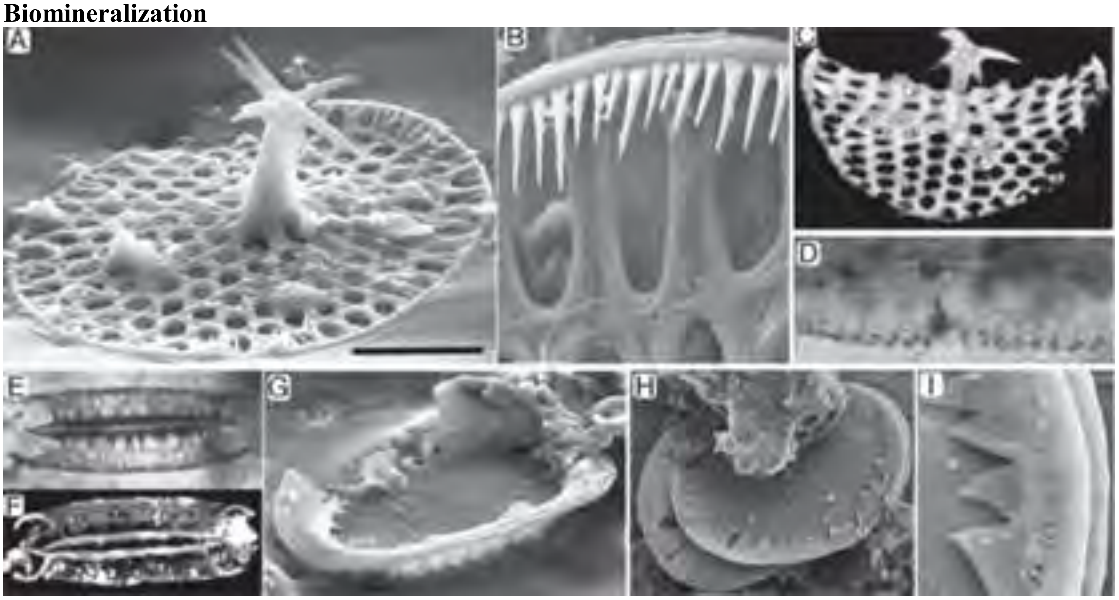
Introduction

"Biomineralization is the process by which living organisms produce minerals, often to harden or stiffen existing tissues. Such tissues are called mineralized tissues. It is an extremely widespread phenomenon; all six taxonomic kingdoms contain members that are able to form minerals, and over 60 different minerals have been identified in organisms." "The most common biominerals are the phosphate and carbonate salts of calcium that are used in conjunction with organic polymers such as collagen and chitin to give structural support to bones and shells. The structures of these biocomposite materials are highly controlled from the nanometer to the macroscopic level, resulting in complex architectures that provide multifunctional properties. Because this range of control over mineral growth is desirable for materials engineering applications, there is significant interest in understanding and elucidating the mechanisms of biologically controlled biomineralization." [1]

Biomineralization Research

A study conducted by the Air Force Research Lab investigated the creation of "anti-bacterial bio-nano-composites of lysozyme with amorphous silica or titania." The study focused on lysozyme ability to "direct the formation of silica or titania nanoparticles under ambient conditions" while being "simultaneously entrapped while in the active bactericidal form." It was also noted that "The ability to encapsulate an active antimicrobial protein within inorganic nanoparticles provides an opportunity to create bionanocomposite materials that resist bacterial activity, for use as broad spectrum antifouling materials." [2]

Biomineralization



From: http://astrobiology.nasa.gov/articles/biomineralization-linking-biology-and-geochemistry
Image courtesy of: NASA

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1. http://en.wikipedia.org/wiki/Biomineralization
2. Luckarift, Heather R. et al, Rapid, Room-Temperature Synthesis of Anti-Bacterial Bio-Nano-Composites of Lysozume With Amorphous Silica or Titania

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Block Coploymer

Introduction

Generally, mass-production fabrication is a top-down process. However, scientific discoveries in the nanosciences have made the concept of self-assembly nanomaterials worthy of re-evaluation. While fairly well developed in the lab, self-assembly does not have the speed and robustness required for use in mass production nanomanufacturing. Specifically, self-assembled patterns contain errors such as pattern defects and roughness on a scale which is unacceptable for use in industry." [1]

Block Coploymer Research

"Nanotechnology can have a profound effect on the delivery of pharmaceuticals with poor bioavailability by improving their stability, circulation times in the body, and permeability through cell membranes." [2] Block copolymers are being used in drug delivery systems. "Symmetrical ABA-type block copolymers, consisting of hydrophilic poly(ethylene glycol) A-blocks and hydrophobic polyarylate oligomers of desaminotyrosyl-tyrosine esters (DTR) and diacid as the B-blocks, self-assemble into spherical structures with hydrodynamic diameters between 50 and 100 nm, thus providing particle size and surface chemical properties superior to conventional drug delivery designs." [2]

Footnotes

1. http://www.nist.gov/cnst/nrg/modeling_simulation.cfm
2. Sheihet, L., Nanospeheric Chemotherapeutic and Chemoprotective Agents [a. b.]

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Sheihet, L., Rutgers The State University, Nanospeheric Chemotherapeutic And Chemoprotective Agents, 09 March 2011, DA375059.

Capacitance

Introduction

"In electromagnetism and electronics, capacitance is the ability of a body to hold an electrical charge. Capacitance is also a measure of the amount of electrical energy stored (or separated) for a given electric potential. A common form of energy storage device is a parallel-plate capacitor. In a parallel plate capacitor, capacitance is directly proportional to the surface area of the conductor plates and inversely proportional to the separation distance between the plates. "[1]

Capacitance Research

The "quantum capacitance of graphene" was measured in a Manchester University study whose goal was the development of graphene-based electronics. These measurements were able to "demonstrate new devices with variable capacitance." Further, the exploration of the roughness of graphene membranes "demonstrated that nanoscale roughness is intrinsic, even if no adsorbates are present." [2]

Footnotes

1. http://en.wikipedia.org/wiki/Capacitance
2. Geim, Andre, Towards Graphene-based Electronics

References

From the Research Summaries database

Geim, Andre, Manchester University, Towards Graphene-based Electronics, 01 February 2011, DF701553.

Carbon Black

Introduction

A form of amorphous carbon that has a high surface-area-to-volume ratio and is used as a pigment and reinforcement in rubber and plastic products. [1]

Carbon Black Research

Researchers at the Army Research Laboratory used heat-treated element compounds as a catalyst for oxygen reduction to engage catalyst on carbon black, which in turn reduces discharge polarization on lithium-dioxide compounds.[2]

Footnotes

1. http://en.wikipedia.org/wiki/Carbon_black
2. Zhang, Sheng S. et al, Heat-Treated Metal Phtalocyanine Complex as Oxygen Reduction Catalyst for Non-Aqueous Electrolyte Li/air Batteries

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Zhang, Sheng S.; Ren, Xiaoming; and Read, Jeffrey, Army Research Laboratory, Heat-Treated Metal Phtalocyanine Complex as Oxygen Reduction Catalyst for Non-Aqueous Electrolyte Li/air Batteries, January 2011, ADA541935, http://handle.dtic.mil/100.2/ADA541935.

Chemical Vapor Deposition

Introduction

"Chemical Vapor Deposition (CVD) is a chemical process used to produce high-purity, high-performance solid materials." The semiconductor industry uses CVD to produce thin films. In the typical process, "the wafer (substrate) is exposed to one or more volatile precursors, which react and/or decompose on the substrate surface to produce the desired deposit." Microfabrication processes widely use CVD to deposit materials in various forms, such as carbon nanofibers.[1]

Chemical Vapor Deposition Research

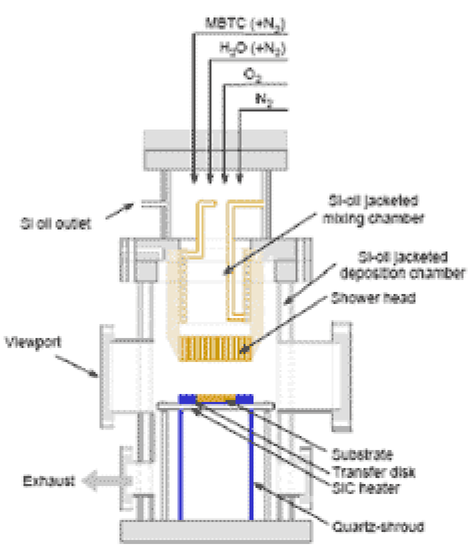
In research done for the Army, "complementary metal-oxide semiconductor (CMOS) compatible optical intra-chip data communication systems would enable this data flow by increasing data rates and reducing circuit size and power." The semiconductor uses "Si-rich oxide films [were] deposited by reactively sputtering Si in the presence of oxygen, plasma enhanced chemical vapor deposition (PECVD), and low pressure chemical vapor deposition (LPCVD)."[2]

A study was conducted to "prepare and characterize graphene via chemical vapor deposition for large area transferrable graphene, and microwave plasma-enhanced chemical vapor deposition for graphene nanowalls."[3]

U.S. Army Research Laboratory (ARL) has been studying the capabilities of graphene growth. The study was able to achieve "world's highest reported fT for a graphene field-effect transistor (GFET) fabricated from chemical vapor deposition (CVD)-grown graphene; and a first-generation graphene-based supercapacitor." [4]

Chih-Chung Yang conducted a study on "Au nanoparticles (NPs) of fixed orientation on sapphire." Yang concluded that "helical deposition of InGaN with a quasi-periodical indium content distribution along the growth direction for growing InGaN nanoneedles with the vapor-liquid-solid growth mode by using Au nanoparticles, which are formed on a GaN template with pulsed laser irradiation, as catalyst in a metalorganic chemical vapor deposition reactor is deduced." [5]

Schematic of Stagnation-Flow Chemical Vapor Deposition Reactor



From: **http://www.sandia.gov/microfluidics/staff-pages/mdallen/research/chem-vapor.php**
Image courtesy of: Sandia National Laboratories

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1. http://en.wikipedia.org/wiki/Chemical_vapor_deposition
2. Chen, Kuei-Hsien, Graphene Nanowalls as Ingenious Material for Catalysts and Superconductors
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Yang, Chih-Chung, National Taiwan University, Formation of Sphere-like Au Nanoparticles on Substrate with Laser Illumination and Their Surface Plasmon Behaviors, 17 September 2010, ADA529223, http://handle.dtic.mil/100.2/ADA529223.

Cluster Beam Deposition

Introduction

Cluster Beam Deposition offers "a means of depositing high quality thin films at low substrate temperature for microelectronics fabrication." An advantage of using cluster beam deposition is "the ability to optimize the energy of the impacting particles, either directly in clustered vapors of nonvolatile materials or indirectly by bombarding the film during deposition with clusters of insert gases. When a cluster beam is ionized and accelerated through several thousand volts, cluster that contain 1000 or more atoms strike the surface with several electron volt energy per atom."[1]

Footnotes

1. Knauer, W et al, Cluster Beam Studies

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From the Technical Reports database

Knauer, W. and Poeschel,R.L., Hughes Research Labs, Cluster Beam Studies , October 1986, ADA176803, http://www.dtic.mil/docs/citations/ADA176803.

Comminution

Introduction

Comminution is the process in which solid materials are reduced in size, by crushing, grinding and other techniques. It is an important operation in mineral processing, ceramics, electronics and other fields. Within industrial uses, the purpose of comminution is to reduce the size and to increase the surface area of solids. It is also used to free useful materials from matrix materials in which they are embedded, and to concentrate minerals. [1]

Comminution in Nanotechnology

Comminution as it relates to nanotechnology is the mechanical reduction of micrometer-sized particles for generating nanoparticles of soft materials. Comminution takes place at cryogenic temperatures with solid carbon dioxide as additive to decrease agglomeration by cold welding and to generate nanometer-size particles. [2]

Different Types of Comminution:

- **Abrading**: Abrading is the controlled process of scratching, wearing down, marring, or rubbing away the surface of a nanomaterial. It can be intentionally imposed in a controlled process using an abrasive.
- **Powder processing**: Powder processing is the process of blending fine particle nano-materials, pressing them into a desired shape and then heating the compressed material in a controlled atmosphere to bond the material (sintering).
- **Pounding/Crushing** is the process whereby nanoparticles are grounded into smaller particles using an industrial process. [2]

Comminution Research

The surface figure error on mirrors can be divided into low, mid, and high spatial frequency errors. Conventional optical aberrations are represented by the low frequency errors. Finish (also gloss or roughness) are described by the high frequency errors. Mid frequency errors are typically the cause of small angle scattering. A process called VIBE, which uses a vibrating lap, was applied to flat borosilicate glass surfaces for up to 60 seconds. Only nanometers of material were removed. Tens of compliant polishing pads were evaluated with the technique. The power spectral density was used to evaluate frequency content. Initial results indicate that VIBE finishing can reduce the midfrequency errors on flats. [3]

This report results from a contract tasking University of Southampton as follows: The main objectives of this exploratory, short project will concern the study of the quality of liquid crystal cells with diluted suspensions of ferroelectric nanoparticles and their photorefractive properties. We will use ferroelectric nanoparticles of photorefractive material: thiohypodiphosphate (Sn2P2S6). The actual nano-particles have been produced by a method (fine mechanical grinding) that was tested earlier. Sn2P2S6 nanoparticles proved, so far, to be the most efficient in enhancing dielectric anisotropy of liquid crystals. As liquid crystal hosts, Merck E7 or ZLI 4801 will be used and cells will be prepared in two configurations. The first configuration will have standard, non-photosensitive aligning layers on both substrates, such as polyimide or low-ionic surfactant. The second configuration will include a photosensitive PVK:C60 layer on one substrate of the cell, instead of polyimide. The LC DSFNP cells with the highest quality will be tested for two-beam coupling gain and the magnitude of diffraction. [4]

A Starret PREMIS HGDC 2018-16 direct computer controlled (DCC) coordinate measuring machine (CMM) was purchased and installed in the metrology lab of the Center for Optics Manufacturing (COM) at the University of Rochester. This CMM was a valuable addition to our facility; it allowed for the precise measurement of ground surfaces on a variety of parts generated on the Moore Precision Tools Nanotech 150AG Aspharic Grinder and the Nanotecnnologv Systems Nanotech 5OOFG Freeform Generator. The unique and complex nature of these parts prevented them from being characterized with standard optical metrology instrumentation. The acquisition of this CMM has opened up new opportunities for collaborations with Army programs. [5]

Footnotes

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3. Nelson, J.; Light, B.; Wiederhold, R.; and Mandina, M, Eliminating Mid-Spatial Frequency (MSF) Errors with VIBE Finishing
4. Kaczmarek, Malgosia, Nanoparticles Doped, Photorefractive Liquid Crystals
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Kaczmarek, Malgosia, Southampton University, Nanoparticles Doped, Photorefractive Liquid Crystals, September 2005, ADA454768, http://handle.dtic.mil/100.2/ADA454768.

Nelson, J.; Light, B.; Wiederhold, R.; and Mandina, M., Optimax Systems Inc., Eliminating Mid-Spatial Frequency (MSF) Errors with VIBE Finishing, June 2010, ADA536350, http://handle.dtic.mil/100.2/ADA536350.

Conductivity

Introduction

"Electrical conductivity or specific conductance is the reciprocal quantity, and measures a material's ability to conduct an electric current."[1]

Conductivity Research

Conductivity testing is conducted in a wide range of studies including the following:

- Investigation of "tuning thermal and electrical conductivities in structure-engineered nanowires for high-efficiency thermoelectric devices." [2]
- Investigation of "thermal conductivity in nano structures with existing defects, understand the role of phonon scattering under resonance and also understand the role of electron and phonon contributions to the thermal conductivity" in 1-D and 2-D nanostructures. [3]

Semiconductivity

"A semiconductor is a material with electrical conductivity due to electron flow (as opposed to ionic conductivity) intermediate in magnitude between that of a conductor and an insulator. This means conductivity roughly in the range of 103 to 10−8 siemens per centimeter." [4]

Nanoparticles "of various origins such as dielectric, electroconductive, semiconductive, and magnetic" were used for "building reconfigurable networks within the liquid crystal" in a study which attempted to demonstrate "the feasibility of multi-functional highly nonlinear materials for photonics and optoelectronics." [5]

Superconductivity

"Superconductivity is a phenomenon of exactly zero electrical resistance occurring in certain materials below a characteristic temperature like ferromagnetism and atomic spectral lines, superconductivity is a quantum mechanical phenomenon." [6]

One study which investigated "high-temperature superconductivity state in metallic nanoclusters" examined the "tunneling networks formed by certain nanoclusters that possess high transition temperature (tc) values." The study noted that "A network formed out of such clusters will be able to transfer a macroscopic superconducting current." [7]

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Cryomilling

Introduction

Cryomilling, also known as freezer milling, freezer grinding, is the act of cooling or chilling a material and then reducing it into a small particle size. Cryomilling is a variation of mechanical milling, in which metallic powders or other samples (e.g. temperature sensitive samples and samples with volatile components) are milled in a cryogen (usually liquid nitrogen or liquid argon) slurry or at a cryogenics temperature under processing parameters, so a nanostructured microstructure is attained. Cryomilling takes advantage of both the cryogenic temperatures and conventional mechanical milling. The extremely low milling temperature suppresses recovery and recrystallization and leads to finer grain structures and more rapid grain refinement. The embrittlement of the sample makes even elastic and soft samples grindable. Tolerances less the 5 um can be achieved. The ground material can be analyzed by a laboratory analyzer. [1]

Cryomilling Research

Aerospace: Cryomilled aluminum alloys are being developed for aerospace applications. These high-strength aluminum alloys are currently targeted for low-temperature rocket applications. Research is being focused on the fundamental strengthening mechanisms in these alloys. The primary sources of strengthening in cryomilling aluminum alloys are dispersion of nanocrystalline particles and ultrafine grain size that form during the cryomilling stage. [2]

High Strength Composite Materials: Cryomilled nanocrystals are being used to develop and synthesize new bulk light-weight materials with desirable microstructural features and optimal structural combinations (e.g., nanocrystalline, amorphous, multiphase) that can endow the material with ultrahigh strength for future Army systems. Research efforts have been devoted to the synthesis and characterization of nanostructured Ti and Mg and Al nanocomposites (reinforced with amorphous particles), and the primary accomplishments are described in the referenced report. [3]

High Temperature Thermal Control Coatings: Cryomilling of NiAl is helping to develop new longer lasting, higher temperatures bond coatings to improve the performance of gas turbine engine components. Cryomilled Nickel aluminide (NiAl) has excellent high-temperature oxidation resistance and can sustain a protective AI203 scale to longer times and higher temperatures in comparison to MCrAIY alloys. [4]

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Dendrimers

Introduction

A dendrimer is a branched, large molecule that is usually spherical with a three-dimensional morphology. The dendrimer is symmetric around its core and often times used interchangeably with dendron. A dendron, however, is a single part of a dendrimer and usually contains the focal point. [1]

Dendrimers Research

Dendrimers are used primarily in chemistry with other chemicals functioning as detecting agents like dye. They have also been studied as an approach for drug delivery, in gene delivery without damaging DNA, which makes dendrimers useful in research treating cancer, and also for use in sensor technologies.
Dendrimers are being used in research to:

- splice breast cancer cells to allow for slight modifications with live morpholino oligonucleotides that affect tumor growth in vivo [2]
- deliver therapeutics and imaging agents in-vitro using normal cells and breast cancer cell lines for tracking tumor growth [3]
- synthesize biofunctional ligands with longer linkers in order to mediate tumor killing in cells in-vitro [4][5]
- target and deliver proapoptic genes to breast cancer cells for sensitizing drug-resistant breast cancer cells for chemotherapy [6]
- create contrast in imaging studies for early detection, intraoperative guidance of resections, and postoperative evaluations [7][8]
- induce tumor cell death through thermally ablative temperatures [9]

Footnotes

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3. McFadden, I., Folate-Targeted Proteolytic Macromolecules for Targeted Drug Delivery and Optical Tumor Imaging
4. Kiessling, L., Ovarian Cancer Immunotherapy Using Redirected Endogenous Anti-gal Antibody
5. Sondel, P., Ovarian Cancer Immunotherapy Using Redirected Endogenous Anti-gal Antibody
6. Palakurthi, S., Novel Targeting Approach for Breast Cancer Gene Therapy
7. Tsien, R., Targeting Contrast and Therapeutic Agents to Tumors via Selective Unleashing of Polycationic Uptake Peptides
8. Ronen, S., Molecular and Functional Magnetic Resonance Imaging of Vasulature and PDGFR-Expressing Neovasculature and Tumor in Prostate Cancer Bone Metastases
9. Torti, S., Targeted Nanoparticles for Kidney Cancer Therapy

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McFadden, I., Vanderbilt University, Folate-Targeted Proteolyic Macromolecules for Targeted Drug Delivery and Optical Tumor Imaging, 29 March 2011, DA362207.

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Ronen, S., University of Texas-Houston, Molecular and Functional Magnetic Resonance Imaging of Vasculature and PDGFR-Expressing Neovasculature and Tumor in Prostate Cancer Bone Metastases, 24 June 2011, DA374903.

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Torti, S., Wake Forest University, Targeted Nanoparticles for Kidney Cancer Therapy, 13 September 2010, DA701695.

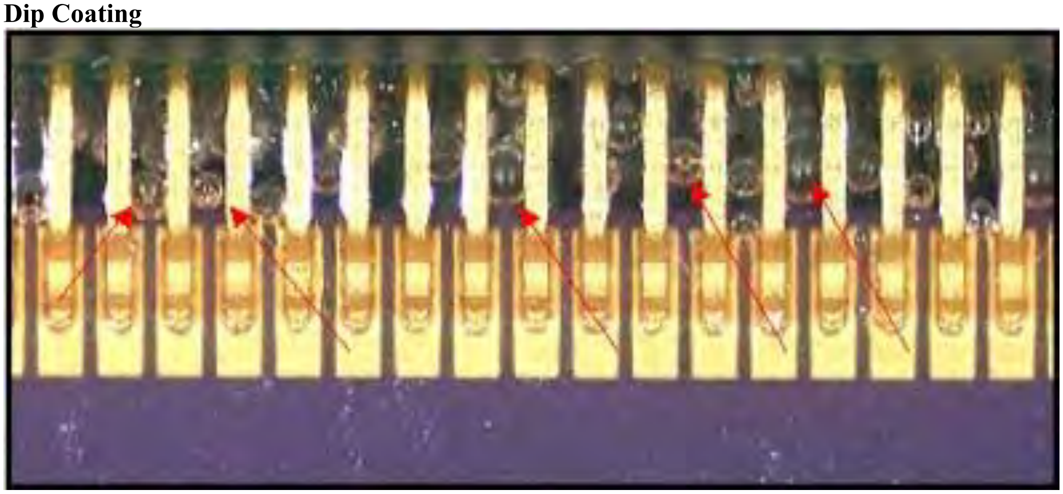
Dip Coating

Introduction

Dip coating is a five step process which creates thin films. The five steps are a continuous process:

- "Immersion: The substrate is immersed in the solution of the coating material at a constant speed (preferably jitter-free)."
- "Start-up: The substrate has remained inside the solution for a while and is starting to be pulled up."
- "Deposition: The thin layer deposits itself on the substrate while it is pulled up. The withdrawing is carried out at a constant speed to avoid any jitters. The speed determines the thickness of the coating (faster withdrawal gives thicker coating material)."
- "Drainage: Excess liquid will drain from the surface."
- "Evaporation: The solvent evaporates from the liquid, forming the thin layer. For volatile solvents, such as alcohols, evaporation starts already during the deposition & drainage steps." [1]

Dip Coating



From: http://nepp.nasa.gov/index.cfm/5694
Image courtesy of: NASA

Dip Coating Research

Areas of research in which dip coating is being used

- Large-Area Self Assembled Monolayers of Silica Microspheres [2]
- Solid phase microextraction (SPME) [3]

Footnotes

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Boglarski, Stephen L., Uniformed Services University of the Health Sciences, Application of Hydrogen Bond Acidic Polycarbosilane Polymers and Solid-Phase Microextraction for the Collection of Nerve Agent Simulant , January 2006, ADA458939. http://handle.dtic.mil/100.2/ADA458939.

Wang, Y.; Chen, L.; Yang, H.; Guo, Q.; Zhou, W.; and Tao, M., University of Texas-Arlington, Large-Area Self Assembled Monolayers of Silica Microspheres Formed by Dip Coating , January 2010, ADA526674, http://handle.dtic.mil/100.2/ADA526674.

Electroless Deposition

Introduction

"Electroless deposition is the process of depositing a coating with the aid of a chemical reducing agent in solution, and without the application of external electrical power. It is therefore applicable to non-conducting substrates, and has been used extensively for metallizing printed wiring boards (PWB)." [1]

Electroless Deposition Research

The areas of research in which Electroless Deposition is being used:

- Ohmic contacts to p-InGaAs [2]
- Si replicas [3]
- Metal/organic self-assembled monolayer/metal junctions [4]

Footnotes

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2. Mohney, Suzanne, Ohmic Contacts for Technology for Frequency Agile Digitally Synthesized Transmitters
3. Sandhage, Ken H. et al, Biomineralized 3-D Nanoparticle Assemblies with Micro-to-Nanoscale Features and Tailored Chemistries
4. Ovchenkov, Y A et al, Metal/Self-Assembled Monolayer/Metal Junctions for Magnetoelectronic Applications

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Ovchenkov, Y.A.; Zhang, Chunjuan; Redepenning, J.; and Doudin, B., University of Nebraska, Metal/Self-Assembled Monolayer/Metal Junctions for Magnetoelectronic Applications , January 2003, ADP014329, http://handle.dtic.mil/100.2/ADP014329.

Sandhage, Ken H. and Lewis, Jennifer A., Georgia Institute of Technology, Biomineralized 3-D Nanoparticle Assemblies with Micro-to-Nanoscale Features and Tailored Chemistries, 07 January 2008, ADA488359, http://handle.dtic.mil/100.2/ADA488359.

Electron Beam Lithography

Introduction

“Electron beam lithography (often abbreviated as e-beam lithography) is the practice of emitting a beam of electrons in a patterned fashion across a surface covered with a film (called the resist), ("exposing" the resist) and of selectively removing either exposed or non-exposed regions of the resist ("developing"). The purpose, as with photolithography, is to create very small structures in the resist that can subsequently be transferred to the substrate material, often by etching. It was developed for manufacturing integrated circuits, and is also used for creating nanotechnology architectures.” [1]

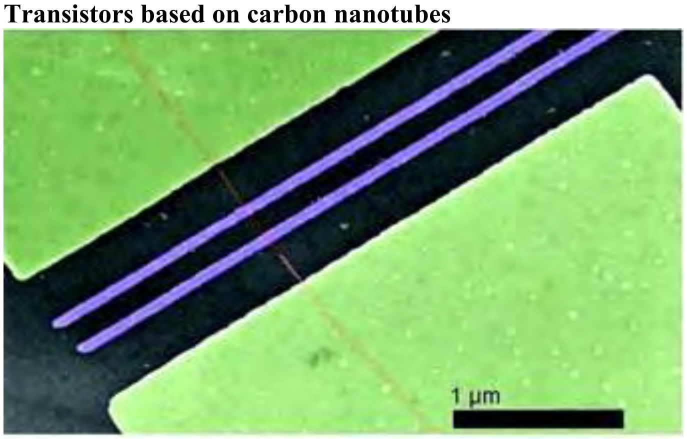
Researchers" are employing chemical vapor deposition, electron beam lithography, and atomic force microscopy to create the nanotube-based devices. They collect measurements at very low temperatures (less than two-hundredths of a degree above absolute zero). The team's research focuses on understanding the role of quantum mechanics in shaping electron flow in carbon nanotubes. Such a knowledge base will be essential in extending the capabilities of device miniaturization. In addition to allowing manufacturers to pack increasingly more switches onto a single chip, device miniaturization via carbon nanotubes may help reduce device power consumption and heat dissipation, which are critical issues for Air Force platforms ranging from manned fighter planes to autonomous drones." [2]

Electron Beam Lithography Research

Risoe National Lab Roskide is exploring the advances of utilizing electron beam lithography. “The advantages of BMG forging are an ability to attain smaller size scales and increased manufacturing speed compared to photolithography, electron beam lithography, and focused ion beam methods. The objectives of the proposed work are to demonstrate the ability to create BMG surfaces with nanoscale surface features, and to establish the capability of existing FEA methods to model BMG flow at these size scales.” [3]

California University Berkeley is researching a “[v]ery large scale integration of Josephson junctions in a two-dimensional series-parallel array has been achieved by ion irradiating a YBa2Cu3O(7-delta) film through slits in a nano-fabricated mask created with electron beam lithography and reactive ion etching. [4

Transistors based on carbon nanotubes



From: http://www.wpafb.af.mil/news/story_print.asp?id=123075237
Image courtesy of: Air Force Print News Today

Footnotes

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2. http://www.wpafb.af.mil/news/story_print.asp?id=123075237
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4. Cybart, Shane A. et al, Very Large Scale Integration of Nano-Patterned YBa2Cu3O7-delta Josephson Junctions in a Two-Dimensional

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Emulsion

Introduction

"An emulsion is a mixture of two or more immiscible (un-blendable) liquids. Emulsions are part of a more general class of two-phase systems of matter called colloids. Although the terms colloid and emulsion are sometimes used interchangeably, emulsion tends to imply that both the dispersed and the continuous phase are liquid. In an emulsion, one liquid (the dispersed phase) is dispersed in the other (the continuous phase)." [1]

Research

One study is making use of "food-grade surfactant, biodegradable oil, water, and ZVI particles (either nano- or micro-scale iron, nZVI, or mZVI)" to form emulsion particles which make up EZVI. EZVI (Emulsified zero-valent iron) is used to "enhance the destruction of chlorinated DNAPL in source zones by creating intimate contact between the DNAPL and the zero-valent iron (ZVI) particles". DNAPSs (dense nonaqueous phase liquids) present a problem because they "act as a long-term source of VOC to groundwater." [2]

Emulsion

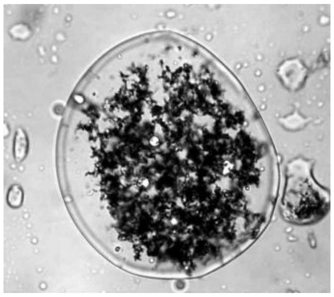

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Image courtesy of: NASA

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Krug, Tom; O'Hara, Suzanne; and Watling, Mark, Environmental Security Technology Certification Program Office (DOD) , Emulsified Zero-Valent Nano-Scale Iron Treatment of Chlorinated Solvent DNAPL Source Areas, September 2010, ADA539928, http://handle.dtic.mil/100.2/ADA539928.

Extreme Ultraviolet Lithography

Introduction

Extreme ultraviolet lithography (also known as EUV or EUVL) is a next-generation lithography technology using an extreme ultraviolet (EUV) wavelength, currently expected to be 13.5 nm. [1]

Extreme Ultraviolet Lithography Research

Colorado State University developed "A high power capillary discharge cadmium plasma source . . . to investigate the generation of 13.2 nm coherent radiation for metrology tasks in Extreme Ultraviolet Lithography." [2]

Sandia National Labs reports on "high power laser plasma Extreme Ultraviolet (EUV) source for Extreme Ultraviolet Lithography. The source is based on the plasma emission of a recycled jet beam of large Xe clusters and produces no particulate debris." [3].

Extreme Ultraviolet Lithography

"Wearing protective clothing, operators work at an E-beam lithography console"
From:
http://www.defenseimagery.mil/imagery.html#a=search&s=%20lithography&guid=269017a07bacb15c7129eec4ac705ea3e7558933
Image courtesy of: Defense Imagery

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Rocca, Jorge J., Colorado State University, Development of a Discharge Pumped 13 nm Laser for Metrology of Projection Lithography Optics at the Manufacture-Site, 14 September 2003, ADA422274, http://handle.dtic.mil/100.2/ADA422274.

Fullerenes

Introduction

Fullerenes are one of two categories of nanomaterials. A fullerene is a molecule fabricated from carbon in a hollow sphere (called buckyballs), tubes (called carbon nanotubes), and ellipsoids. [1]

There are seven types of fullerenes:

- Buckyball clusters
- Nanotubes
- Megatubes
- Polymers
- Nano-“onions”
- Linked “ball-and-chain” dimers
- Fullerene rings

The most well-known of the fullerenes are carbon nanotubes and buckyballs, the latter having been found in outer space.

Buckyball
From: http://www.lanl.gov/source/orgs/nmt/nmtdo/AQarchive/97winter/fullerenes.html
Image courtesy of: Los Alamos National Laboratory

Fullerenes Research

Fullerenes are being used in research for:

- semiconductors [2]
- providing contrast in MRI-guided therapy [3]
- high performance bulk heterojunction solar cells to create new photovoltaic materials [4]

Footnotes

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Moudgil, B., University of Florida-Gainesville, Functionalized Fullerenes for Cancer Imaging and Therapy, 05 October 2010, DA701578.

Wei, Asian Office of Aerospace Research and Development, Development and Characterization of New Donor-acceptor Conjugated Polymers and Fullerene Nanoparticles for High Performance Bulk Heterojunction Solar Cells, 11 August 2010, DF298893.

Inductance

Introduction

"Inductance is the property of an electrical circuit causing voltage to be generated proportional to the rate of change in current in a circuit. This property also is called self-inductance to discriminate it from mutual inductance, describing the voltage induced in one electrical circuit by the rate of change of the electric current in another circuit."[1]

Inductance Research

The objective of one study was to "develop and investigate a phase-sensitive microwave amplifier based on a two-cell superconducting quantum interference device (squid) embedded into a superconducting resonator." The study used a "superconducting coplanar-waveguide resonator modulated by two simultaneously applied phase-shifted external signals at a frequency fs 2f transmitted via oscillating magnetic fluxes threading two different cells of the squid." These fluxes were found to "parametrically change the inductance of the cavity leading to a change of amplitude and phase of the pump signal at frequency fp f transmitted through the cavity."[2]

Footnotes

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References

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Interference Lithography

Introduction

“Interference lithography (or holographic lithography) is a technique for patterning regular arrays of fine features, without the use of complex optical systems or photomasks. The basic principle is the same as in interferometry or holography. An interference pattern between two or more coherent light waves is set up and recorded in a recording layer (photoresist). This interference pattern consists of a periodic series of fringes representing intensity minima and maxima. Upon post-exposure photolithographic processing, a photoresist pattern corresponding to the periodic intensity pattern emerges.” [1]

“For 2-beam interference, the fringe-to-fringe spacing or period is given by $(\lambda/2)/\sin(\theta/2)$, where λ is the wavelength and θ is the angle between the two interfering waves. The minimum period achievable is then half the wavelength.” [1]

“By using 3-beam interference, arrays with hexagonal symmetry can be generated, while with 4 beams, arrays with rectangular symmetry are generated. Hence, by superimposing different beam combinations, different patterns are made possible." [1]

Interference Lithography Research

The objective of this study by the Air Force Institute of Tech Wright-Paterson AFB “is to develop unique holograms on a semiconductor-metal thin films to characterize as potential metamaterials. This is achievable by developing a fabrication recipe to include exposure methods, exposure dosages, and material development. This study developed an interference lithography capability at AFIT for the first time with period resolution below 230nm.” [2]

Footnotes

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Langmuir-Blodgett

Introduction

"A Langmuir-Blodgett film contains one or more monolayers of an organic material, deposited from the surface of a liquid onto a solid by immersing (or emersing) the solid substrate into (or from) the liquid."[1]

The Langmuir-Blodgett technique is when "the monolayers are assembled vertically and are usually composed of amphiphilic molecules with a hydrophilic head and a hydrophobic tail."[2]

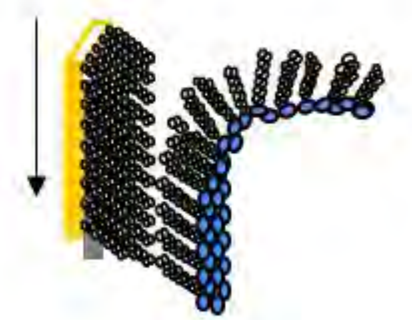
"A Langmuir-Blodgett trough is a laboratory apparatus that is used to compress monolayers of molecules on the surface of a given subphase and measures surface phenomena due to this compression."[3]

Langmuir-Blodgett Research

The areas of research in which the Langmuir-Blodgett technique is being used are:

- Bacteria-phage interactions [4]
- Macrocyclic compounds as electronic materials [5]

Langmuir-Blodgett film



From: http://www.nist.gov/pml/div685/grp08/supportedmembranes.cfm
Image courtesy of the National Institute of Standards and Technology (NIST)

Footnotes

1. http://en.wikipedia.org/wiki/Langmuir%E2%80%93Blodgett_film
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3. http://en.wikipedia.org/wiki/Langmuir-Blodgett_trough
4. Guntupalli, Rajesh et al, Specific Recognition and Detection of MRSA Based on Molecular Probes Comprised of Lytic Phage and Antibody
5. Ray, Asim K., Design of Novel Organic Thin Film Transistors for Wearable Nanoelectronics

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Guntupalli, Rajesh; Olsen, Eric; Globa, Ludmila; Bosarge, Jacob; Moore, Timothy; Sorokulova, Iryna; and Vadyanoy, Vitaly, Air Force Medical Group, Specific Recognition and Detection of MRSA Based on Molecular Probes Comprised of Lytic Phage and Antibody, 29 March 2011, ADA540436, http://handle.dtic.mil/100.2/ADA540436.

Ray, Asim K., Queen Mary College, Design of Novel Organic Thin Film Transistors for Wearable Nanoelectronics, 25 September 2009, ADA535299, http://handle.dtic.mil/100.2/ADA535299.

Laser Ablation

Introduction

Laser Ablation "is the process of removing material from a solid (or occasionally liquid) surface by irradiating it with a laser beam. At low laser flux, the material is heated by the absorbed laser energy and evaporates or sublimates. At high laser flux, the material is typically converted to plasma." [1]

Laser Ablation Research

The electronic properties of arrays of carbon nanotubes from several different sources differing in the manufacturing process used with a variety of average properties such as length, diameter, and chirality [were] studied. Transport measurements were performed to compare and determine the effect of different surfactants, deposition processes, and synthesis processes on nanotubes synthesized using CVD, CoMoCAT, laser ablation, and HiPCO. [2]

Laser Ablation

From:http://www.defenseimagery.mil/imagery.html#a=search&s=laser%20ablation&guid=cce7decf9fef464fd1767ffbf74476b60c09ceb1
Courtesy of: Defense Imagery

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Mechanosynthesis

Introduction

"Mechanosynthesis is any chemical synthesis in which reaction outcomes are determined by the use of mechanical constraints to direct reactive molecules to specific molecular sites." [1]

Mechanosynthesis Research

The Mechanosynthesis process has applications in the following area:

- Production of "materials classes' cermets, particulate metal matrix composites (mmc), and tungsten heavy alloys." [2]

Footnotes

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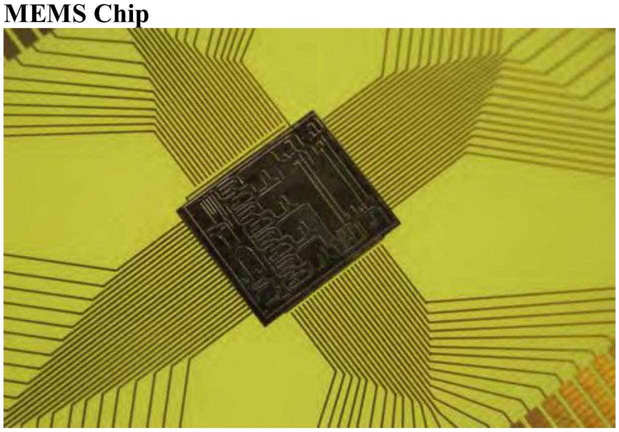
Microelectromechanical Systems

Introduction

Microelectromechanical systems (MEMS) have a large array of applications. Microelectromechanical systems “are made up of components between 1 to 100 micrometres in size.” “MEMS devices generally range in size from 20 micrometres to a millimetre.” MEMS “usually consist of a central unit that processes data, the microprocessor and several components that interact with the outside such as microsensors.” [1]

MEMS Chip



From:http://www.genome.gov/pressDisplay.cfm?photoID=20017
Courtesy: National Human Genome Research Institute

Microelectromechanical Systems Research

Microelectromechanical systems are used as implants for denervated muscles. In a study conducted at California University, MEMS technology was used to “design an indwelling hybrid microstimulator.” This study sought to “develop a hybrid implantable microstimulator system that can be used in a novel therapeutic strategy for denervated muscles by mimicking the natural stimulation that occurs at neuromuscular junctions.” These microelectronics were designed to be “small enough to be integrated into an implantable system and that can deliver current-based electrical stimulation.” [2]

Devices a millimeter or sub-millimeter in length which have the capability to perform “physiological monitoring, threat alert, internal stimulation, and drug-delivery” are being developed using MEMS for the armed forces population. Such devices also have applications as a “communication and power delivery channel capable of passing information between the inside and the outside of the human body.” The ability to monitor the “physiological status” of a soldier and communicate this information outside the body may prove highly beneficial on the battlefield. [3]

Another study looked toward MEMS technology as basis for the development of an implantable device for drug delivery. The device, called “IRD3 (implantable rapid drug delivery device)”, was designed for use in “ambulatory emergency care.” IRD3 provided successful results as “an effective method for rapid delivery without significant drug degradation.” [4]

The Deformable mirrors of Microelectromechanical systems provide a means of “correcting aberrations in space-based optical imaging systems.” These systems are “ideal for space based adaptive optics” because of their “small size, weight, and power requirements”. [5] Yet another advantage of working with MEMS systems is their “magnetic, angular rate, and gravity (MARG) sensors.” These sensors have numerous military and civilian applications including “personal navigation” and “immersive virtual reality training” and are already being used in systems such as the Nintendo Wii as well as the Apple iPhone. [6] Lastly, MEMS have an application in improving “operating characteristics of rolling-element bearings”. A 2010 study pursued this improvement through the “development and implementation of MEMS (Micro Electro-Mechanical System) based strain sensors.” [7]

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3. Errigo, Brian D, et al. Volume Conduction Invasive Medical Data Communication System. Phase I
4. Elman, N. et al, An Implantable Drug Delivery Device for Rapid Delivery in Ambulatory Emergency Care
5. Cornelissen, Steven, High Actuator Count MEMS Deformable Mirrors for Space Telescopes
6. Cookson, Jeremy, L., A Method for Testing the Dynamic Accuracy of Micro-Electro-Mechanical Systems (MEMS) Magnetic, Angular Rate, and Gravity (MARG) Sensors for Inertial Navigation Systems (INS) and Human Motion Tracking Applications
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Molecular Beam Epitaxy

Introduction

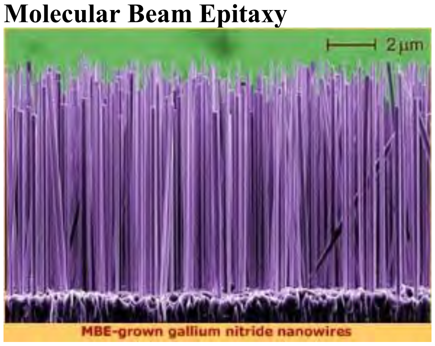
"Molecular Beam Epitaxy (MBE) is one of several methods of depositing single crystals."
"Molecular beam epitaxy takes place in high vacuum or ultra-high vacuum (10^{-8} Pa). The most important aspect of MBE is the slow deposition rate (typically less than 1000 nm per hour), which allows the films to grow epitaxially. The slow deposition rates require proportionally better vacuum to achieve the same impurity levels as other deposition techniques." [1]

Molecular Beam Epitaxy Research

The areas of research in which Molecular Beam Epitaxy is being used:

- "Tin-Based IV-IV Heterostructures" [2]
- "Grow high dielectric constant oxides on InGaAs and GaN" [3]
- "Developing high quality mercury cadmium telluride (HgCdTe)/silicon (Si)" [4]

Molecular Beam Epitaxy



From: http://www.boulder.nist.gov/div815/SGD_Project/Accomplishments.htm
Image courtesy of: National Institute of Standards and Technology

Footnotes

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Molecular Devices

Introduction

Molecular devices “build on materials and systems whose structures and components as well as their physical, chemical or biological properties can be designed at a molecular level to efficiently perform a useful function.” [1]

Molecular Devices Research

In order to create “polypeptides based molecular electronics,” the “transportation properties in molecular devices” was investigated. Additional research for this project included investigation of “methodologies for creating molecular wires using polypeptides nanofibrils” as well as “methodologies for new device fabrication concepts through the use of self-assembly.”[2]

Creation of “three dimensional memory and logic molecular devices” was the topic of investigation of one recent study. Researchers were able to manufacture a molecular memory transistor “based on the concept of the vertical transistor, in which a side gate is used to activate a vertically-patterned molecular active-channel layer.”[3]

Molecular Devices

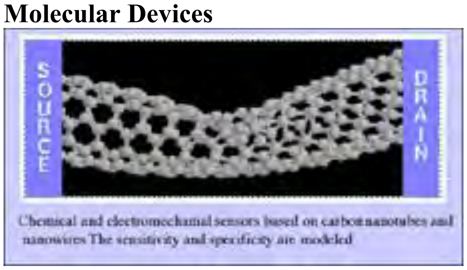

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Image courtesy of: NASA

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Richter, Shachar E., Tel-Aviv University, Construction and Operation of Three Dimensional Memory And Logic Molecular Devices, 24 June 2010, DF701600.

Molecular Electronics

Introduction

Molecular electronics is “the study and application of molecular building blocks for the fabrication of electronic components.” Some examples of molecular electronics are the “applications of conductive polymers, and single-molecule electronic components for nanotechnology.” [1]

Molecular Electronics Research

“DNA strand between metal atom contacts could function as a molecular electronics device”

From: http://www.nasa.gov/vision/earth/technologies/27jul_nanotech.htmlh1. Molecular Electronics in Research

Image courtesy of the NASA Ames Center for Nanotechnology

Another study used the “recent technological breakthroughs in the fields of nanomechanics and nano- and molecular-electronics in order to develop ultra-sensitive mass sensors, capable of detecting the mass of a single small molecule.”[2] Professor Cui had developed “physics-based software on high-performance computing (HPC) platforms for the study of nano/molecular electronics.” This software can produce large DNA arrays in 3D. The software has helped make some key advancement including “self-assembling 3D crystals with multiple components and for making arrays of DNA origami crystals.”[3] Another study used a “molecular electronic drive applications of carbon nanotube multi-terminal junctions in the form of T- and Y-junctions.”[4]

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Molecular Mechanics

Introduction

Molecular mechanics is a way to model all potential energy of all systems by calculated use of force fields. The method can be used to study molecules to large biological systems. There are three properties that all atomistic molecular mechanics methods have:

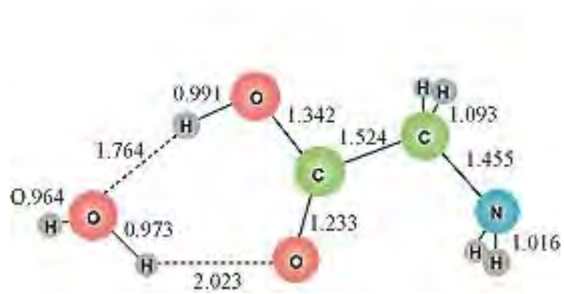
- "Each atom is simulated as a single particle"
- "Each particle is assigned a radius, polarizability, and a constant net charge"
- "Bonded interactions are treated as "springs" with an equilibrium distance equal to the experimental or calculated bond length" [1]

Molecular Mechanics Research

The areas of research in which molecular mechanics is used:

- Ceramics and/or semiconductors [2]
- Bithiophene/thieno polymer [3]
- Superelasticity [4]
- Gold nanorods [5]
- Mechanical properties of nanoconfined water layers [7]

Molecular mechanics technique



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Wei, Kung-Hwa and Jen, Alex K., National Chiao Tung University, Development and Characterization of New Donor-Acceptor Conjugated Polymers and Fullerene Nanoparticles for High Performance Bulk Heterojunction Solar Cells, 14 January 2011, ADA535169.

Molecular Modeling

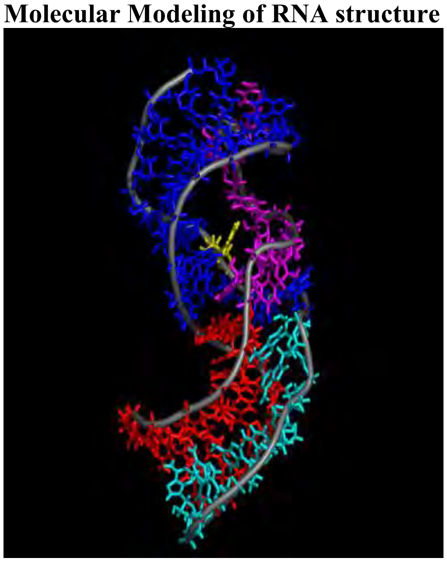
Introduction

Molecular Modeling is made up of "theoretical methods and computational techniques used to model or mimic the behavior of molecules." Fields that use these techniques are computational chemistry, computational biology and materials science. A technique that is under molecular modeling is molecular mechanics. [1]

Molecular Modeling Research

"Molecular modeling has been used in order to understand the water absorption characteristics of polybenzimidazole (PBI) and its effect on mechanical properties." [2]

Molecular Modeling of RNA structure



From: http://www-lmmb.ncifcrf.gov/~bshapiro/telomerase/telomerase.html
Image courtesy of the Center for Cancer Research, National Cancer Institute

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Molecular Motor

Introduction

Molecular Motors, also known as biomotors, are “biological molecular machines that are the essential agents of movement in living organisms.” [1]The “molecular motor utilizes chemical free energy to generate a unidirectional motion through the viscous fluid.”[2][3]

Molecular Motor Research

“In many experimental settings and biological settings, a molecular motor is elastically linked to a cargo. The stochastic motion of a molecular motor-cargo system is governed by a set of Langevin equations, each corresponding to an individual chemical occupancy state.” A molecular motor is “is governed by a two-dimensional Fokker-Planck equation” and operated “by high viscous friction and large thermal fluctuations from surrounding fluid. The instantaneous velocity of a molecular motor is highly stochastic.” The report shows that “the theory for macroscopic motors should not be applied directly to molecular motors without close examination.” [4]

In another study, a “microscopy system was acquired for molecular detection using molecular motor-driven nanodevices.” The “system utilizes the molecular motor attached to a slide and a gold nanorod that is visible by darkfield microscopy.” [5]

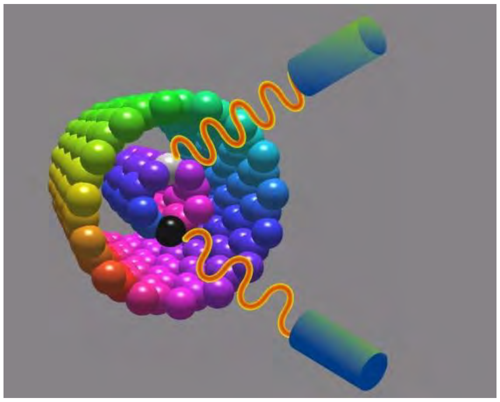
Researchers “calculated the friction coefficients and their dependence on rotation frequency in carborane rotors and propellers.” Found that “molecular rotors can be used to control friction of surfaces to some extent,” and “A new phenomelogical model of molecular propeller action was designed.”[6] Another study, “immobilized F1-atpase molecular motor and a functionalized gold nanorod via a single 3',5'-dibiotinylated DNA molecule.”[7]

Biomotor Research

Biomotor and biosensor nanotechnologies were implemented in the creation of “nanoscale actuators for use as molecular shuttles in biosensing devices.” Research made possible the use of “motors and modified substrata to propel and guide motor-coated micro- and nanoparticles using substratum-bound actin filaments with their elongating plus-ends bound to the particle surface.” [8]

Biomotors have great potential in the field of nanotechnology. Motor proteins have promise “for powering or manipulating nanoscale components.” More specifically, “kinesin and myosin biomotors that move along linear biofilaments have been widely explored as active components.”[9]

Molecular Motor



http://www.csm.ornl.gov/SC98/viz/viz2.html
Image courtesy of the Oak Ridge National Laboratory

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Molecular Sensors

Introduction

"Molecular sensor or chemosensor is a molecule that interacts with an analyte to produce a detectable change." Supramolecular analytical chemistry is a term that has been used to "describe the application of molecular sensors to analytical chemistry." [1]

Molecular Sensor Research

Chemosensor

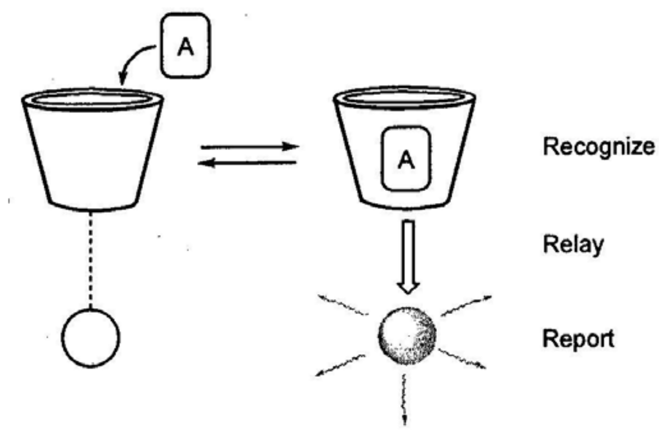

Figure 1. The 3R scheme used for chemosensor development. A = analyte.

From: Nocera, Daniel G., Massachusetts Institute of Technology, Optical Supramolecules for Chemical and Physical Sensing, 02 April 2004, ADA422046

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Molecular Simulation

Introduction

Molecular simulation is the computations used to predict properties of chemicals and materials. These computations are largely computer-based with the advent of such capable technology, and predominantly used in chemistry, pharmacology, materials science, and other related industries.[1] The properties most frequently studied are thermodynamic, thermochemical, spectroscopic, mechanical, and transport properties, however there have also been studies into the morphological properties such as the location and shape of binding sites.[2] An example of a molecular simulation would be to determine the instantaneous positions and velocities of all the molecules in a sample of liquid water.[3]

There are many techniques and types of molecular simulation being used. Two of the most commonly used, as reflected in DTIC's collection, are molecular dynamics and the Monte Carlo simulation. Both are based on statistical mechanics.

Molecular Dynamics

Molecular Dynamics are computer simulations on the physical properties and movements of atoms and molecules. It is most frequently used to study proteins and materials science. Molecular dynamics was originally conceived within the parameters of theoretical physics, however it has become multidisciplinary by employing laws, theories, algorithms and methods from mathematics, information theory, computer science, physics and chemistry.[4]

Monte Carlo Simulation

The Monte Carlo Simulation is a type of simulation that relies heavily on probability. The simulation uses repeated sampling to determine the molecular properties. While there are various types of Monte Carlo methods, all of which are based on probabilistic simulation, they tend to follow a pattern in defining possible inputs, generating inputs randomly from a probability distribution, performing deterministic computations, and aggregating the results.[5]

The method was coined in the 1940s by three scientists working on nuclear weapons projects in Los Alamos and is named after the famed Monaco casino.

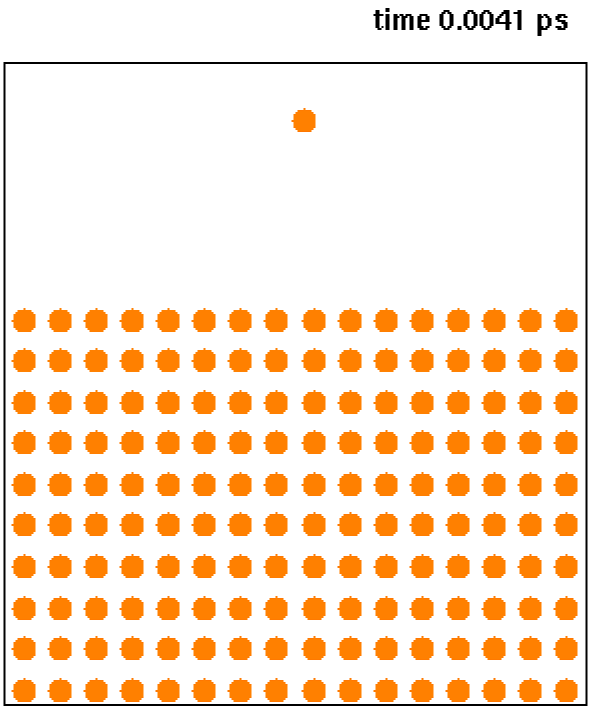
Molecular Simulation Research

Development of Weapons

In a study conducted by Colorado State University with support from the Defense Threat Reduction Agency, molecular simulation was used to assist in the development of a new detection technique that implements a "high sensitivity, field-deployable and cost-effective detector" that recognizes singular molecules and atoms. Based on detecting changes in the oscillation behavior of Individual, or Inherent, Localized Modes (ILMs), it is believed that this new technique will be instrumental in early detection and counter-measures of warfare agents being used in weapons of mass destruction (WMD). The researchers were able to excite ILMs, which is dependent on nanostructures composed of nanoscale elements, and used these results to optimize the design of the arrays within ILMs to visualize their oscillations for optimal performance.[6]

Researchers at Rutgers University, also being supported by the Defense Threat Reduction Agency, have used molecular simulation studies to provide better understandings of the mechanisms governing transport through polymeric electrolyte membranes (PEM) and the interactions of chemical warfare (CW) agents with PEM barriers. Previous research indicated that PEM as permselective diffusion barriers is problematic in engineering new protective materials, as membranes must be impermeable to CW agents while also providing high water vapor permeability, small heat accumulation, and reduced weight. By using simulations, the researchers can help determine better chemical and structural parameters of new synthetic membranes capable of improving current protection against chemical warfare agents.[7]

Deposition of a single Cu atom on a Cu surface



In this example of a molecular dynamics simulation in a simple system, "each circle illustrates the position of a single atom; note that the actual atomic interactions used in current simulations are more complex than those of 2-dimensional hard spheres." From: Molecular Dynamics http://en.wikipedia.org/wiki/File:Cudeposition.gif

Identifying Toxins

Molecular simulation is also beneficial in studies exploring the use of nanotechnology in health. Advanced fluidic and sensor technologies, combined with computational approaches, created "highly instrumented, Automated Multitrap Nanophysiometers (AMTNP) capable of isolating and studying" cells from whole blood and lymph. This allowed direct cellular observation over longer periods of time, which yielded the identification of key signaling molecules, signaling state, and the molecular dynamics of their interactions to use in eventual identification of pathways associated with toxin exposure on a cellular level to aid understanding of pathologies.[9]

Researchers at the University of Wisconsin-Madison are using molecular simulation to assist in development of "molecularly specific optical screening technologies." These new technologies are being used to detect cancer cells before they disseminate in the breast by identifying the earliest signs of cancer which include the "physiological, structural, and molecular alterations" that take place as a cell transforms from normal to malignant. The technology is aided by recent discoveries of new breast-cancer related genes, proteins, and biomarkers to become more sensitive to early pathological changes.[10] For more information on Department of Defense research on breast cancer, see DoD Breast Cancer Research, an "In the News" feature piece.

Additional studies of molecular simulation have been used in constructing and evaluating a probe to be used with a conventional positron emission tomography (PET) to better the spatial resolution and sensitivity of visualizing small prostatic lesions in detecting prostate cancer. By using the Monte Carlo method of molecular simulation, researchers at West Virginia University, the University of Michigan, and the Thomas Jefferson National Accelerator Facility (Jefferson Lab) were able to refine probe requirements and measure, construct, and evaluate the demonstrator probe. This new probe is intended for amplifying resources and tools available for early detection, characterization, and monitoring the treatment of prostate cancer.[11]

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Nanoapplications

Introduction

Nanoapplications are applications that are composed of nanomaterials that are designed to perform a specific task. [1]

Nanoapplications Research

Various research communities have exploited the unique properties of nanomaterials for various applications. These fields include:

Medicine: Researchers are developing customized nanoparticles the size of molecules that can deliver drugs directly to diseased cells in the body. When it's perfected, this method should greatly reduce the damage treatment such as chemotherapy does to a patient's healthy cells. [2]

Fuel Cells: Nanoapplications are being used to reduce the cost of catalysts used in fuel cells to produce hydrogen ions from fuel such as methanol and to improve the efficiency of membranes used in fuel cells to separate hydrogen ions from other gases such as oxygen. [3]

Solar Cells: Nanoapplications are used to manufacture solar cells at significantly lower costs than conventional solar cells. [3]

Batteries: Nanoapplications are used to develop new types of batteries that can be recharged significantly faster than conventional batteries. [4]

Better Air Quality: Nanoapplications are helping to improve the performance of catalysts used to transform vapors escaping from cars and industrial plants into harmless gases. Catalysts made from nanoparticles have a greater surface area to interact with the reacting chemicals than catalysts made from larger particles. The larger surface area allows more chemicals to interact with the catalyst simultaneously, which makes the catalyst more effective. [5]

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Nanobiotechnology

Introduction

"Bionanotechnology and nanobiotechnology are terms that refer to the intersection of nanotechnology and biology. Given that the subject is one that has only emerged very recently, bionanotechnology and nanobiotechnology serve as blanket terms for various related technologies." [1]

"These two terms are often used interchangeably. When a distinction is intended, though, it is based on whether the focus is on applying biological ideas or on studying biology with nanotechnology. Bionanotechnology generally refers to the study of how the goals of nanotechnology can be guided by studying how biological "machines" work and adapting these biological motifs into improving existing nanotechnologies or creating new ones Nanobiotechnology, on the other hand, refers to the ways that nanotechnology is used to create devices to study biological systems." [1]

"Nanobiotechnology is a rapidly advancing area of scientific and technological opportunity that applies the tools and processes of nano/microfabrication to build devices for studying biosystems. Researchers learn from biology to create new micro-nanoscale devices to better understand life processes at the nanoscale." [2]

Nanobiotechnology Research

Vanderbilt University's "study hypothesizes that siRNA]mediated inhibition of NF]B signaling in tumor]associated macrophages (TAMs) will decrease primary tumor growth and metastatic potential. The objectives of this study are:
(1) exploration of macrophage response to inhibition of NF]B activation by the canonical and alternative pathways, separately and in combination using siRNA knockdown in vitro.
(2) Develop a nanobiotechnology delivery vehicle with the capacity for siRNA delivery to TAMs for the purpose of pathway specific NF]B knockdown in vivo." [3]
(3) Develop a scheme for early evaluation of breast cancer neoadjuvant therapy response based on the photoacoustic molecular imaging agents previously developed." [6]

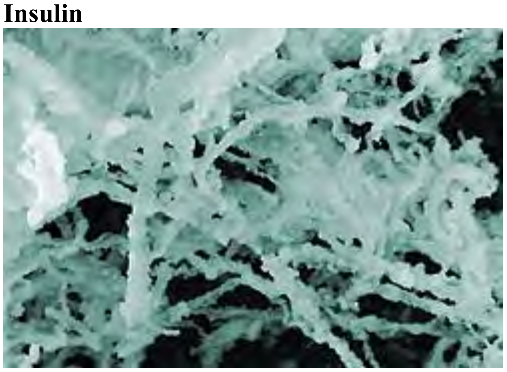
The Asian Office of Aerospace research and Development conducted a study "to investigate Nanoscale Monitoring and Modulation of Auditory Sensing System" The study "is expected that this research will provide better understanding of hair cell signaling process and mechanical properties in molecular basis." [4]

Nanobiotechnology and Breast Cancer

McGill University is utilizing "a nanobiotechnology-based approach for breast cancer vaccine design by incorporating novel design features for antigen delivery and immune system activation. The novel platforms ability to induce antitumor immunity will be assessed." [5]

Stanford University is researching the development and testing of "four photoacoustic imaging agents targeted to four different cancer specific targets.

Insulin



"Insulin, one of the most common proteins in human blood, can accumulate into fibrous masses when it misfolds. Research by a team at NIST indicates that gold nanoparticles apparently increase insulin's tendency to form these fibers. (Color added for clarity.)"

From: http://www.nist.gov/public_affairs/techbeat/tb2010_0112.htm
Image courtesy of: National Institute of Standards of Technology

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Nanocatalysis

Introduction

Nanocatalysis, or nanocatalysts, have many potential military applications including but not limited to advanced propulsion. Like chemical catalysis nanocatalysts can increase the rate of combustion at lower temperatures therefore placing less strain on materials. It has been show that nanocatalysts "form very stable colloidal suspension in fuel can help fuels to ignite lower temperatures, increase their combustion efficiency and increase the heat sink capabilities of fuels." More research needs to be conducted in order to gain a full understanding of the "unique properties of nanostructures as catalysts and develop methods by which they can be exploited in propulsion systems." [1]

Scanning Electron Micrograph (SEM) of the surface of purified, NI-catalyzed MWNT

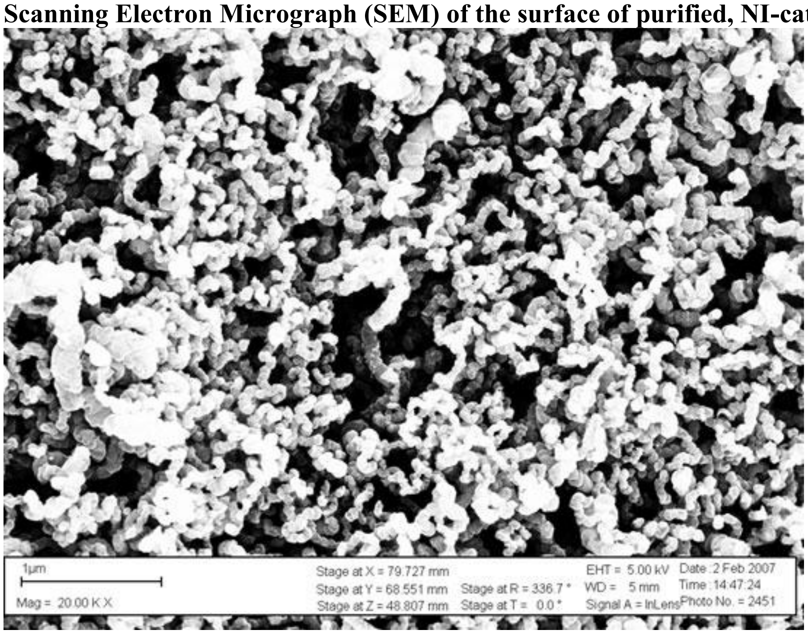

Image Courtesy of the [Naval Research Laboratory](http://www.nrl.navy.mil/pao/pressRelease.php?Y=2008&R=17-08r)
http://www.nrl.navy.mil/pao/pressRelease.php?Y=2008&R=17-08r

"Nanocatalysts are used to begin chemical reactions that change the properties of materials. Many nanoparticles have exceptionally large surface areas relative to the total amount of material, and so they serve as a better catalyst, since a chemical catalyst depends on how much of one substance comes in contact with another. The incredibly small nanoparticles are able to affect catalysts very efficiently in processed reactions. Current experiments are using gel-based nanocatalysts to transform coal into oil products. The use of nanocatalysts as enzyme-like actors in chemical processes was a process supported by scientist Richard Smalley, and such reactions could be used in both biological manipulating and purification processes."[2]

Nanocatalysis Research

At present a Gold nanostructure as catalysts are being researched in various applications. For example, the National Taiwan University Taipei is investigating the influencing factors "catalysis of gold nanoparticles supported on mesoporous silica." [3]

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Nanocrystals

Introduction

Nanocrystals are aggregates of anywhere from a few hundred to tens of thousands of atoms that combine into a crystalline form of matter known as a cluster. Nanocrystals are typically around ten nanometers in diameter, and are larger than molecules but smaller than bulk solids. A nanocrystal is virtually all surface and no interior, and its properties can vary considerably as the crystal grows in size. [1]
Growing flawless nanocrystals is relatively easy because their length of scale is so small; there's simply not enough time during the growth process to introduce defects. However, due to the tiny length of scale, controlling the size and surface of nanocrystals is a tremendous challenge.
According to Paul Alivisatos, a chemist who holds a joint appointment with Berkeley Lab's Material Sciences Division (MSD) and with the Chemistry Department of the University of California at Berkeley, "Nanocrystals are particularly attractive as building blocks for larger structures because it's possible – even easy – to prepare nanocrystals that are highly perfect." [2]

Nanocrystals Research

One of the areas of research where nanostructures are used is in electric power production. Because of the self-cleaning properties of nanoparticles, nanocrystals have been used in naval power generation and detection applications. [3]

Nanocrystals are also being used to transfer large amounts of data from sensors to processors on a wide variety of systems. [4]

Researchers at the Army Research Laboratory are studying nanocrystallines (small clusters of nanocrystals) and ultrafine-grained bulk materials, developed through metallurgy processes though these structures confine the thermal stability of the resulting nanostructures. These researchers, however, have managed to develop a thermally-stable nanocrystalline tungsten powder that appears to reduce the densification rate of pressureless sintering. [5]

Nanocrystallines have also been considered through means of synthetic development, as proposed by researchers at Northwestern University. Through the synthetic development, the researchers discovered a new semiconductor phase stable only when existing on the nanoscale and unstable when existing in bulk, as nanocrystalline structures. [3]

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Nanoelectronics

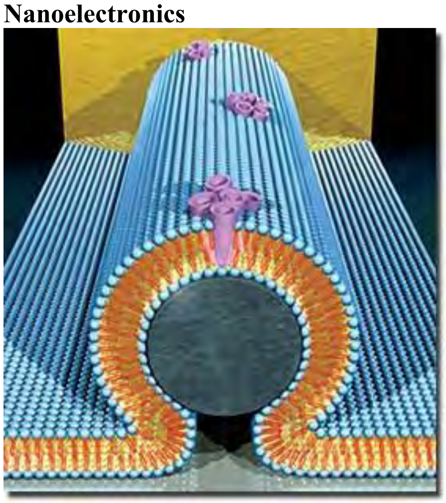
Introduction

Nanoelectronics refer to "the use of nanotechnology on electronic components, especially transistors." Within these transistors, "inter-atomic interactions and quantum mechanical properties" must be applied due to the small size.[1]

Nanoelectronics Research

Nanoelectronics which are capable of "employing carbon nanotubes" have demonstrated promise in their ability to "replace conventional semiconductor devices in the near future." On study examines "the mechanisms of radiation damage in carbon nanotubes as a function of electronic properties and geometric thickness for both ionizing and non-ionizing particles under exposure to high total ionization and displacement damage doses."[2]

Nanoelectronics



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Nanofabrication

Introduction

Fabrication "is the process or manufacture of parts, usually structural or electromechanical. This involves the design of a circuit or device. This can also include the creation of a machine that will be used in the total manufactured product." [1]Nanofabrication is the process of designing and manufacturing of products dimensions measured in nanometers. Nanofabrication deals particularly with electromechanical nanostructures.[2] [3]

Nanofabrication Research

Research at the Army Research Laboratory in Adelphi MD "systematically compares various solution-based electrode fabrication methods (drop casting, air brushing, filtration, and electrospraying) to determine if there is an optimum method for fabricating supercapacitor electrodes out of single-wall carbon nanotubes (SWCNT)."[4]

Nanofabrication

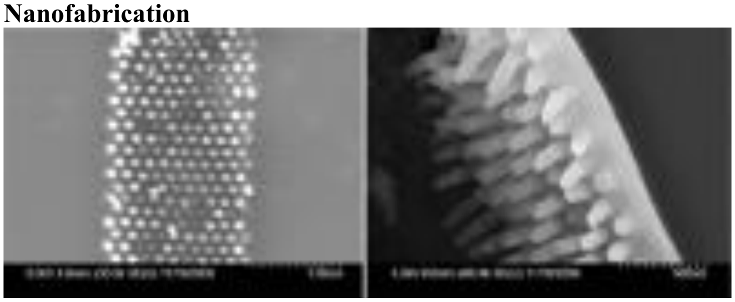

Image courtesy of the US Air Force
"Researchers demonstrated the first-ever nanoimprint-lithography-based fabrication of biopolymer nanostructures. The nanolithography technology will enable low-cost, portable production of communications and sensing devices. Pictured are atomic-force microscope images of a nanoimprinted DNA biopolymer; the diameter of each pillar is 70 nm, and the height is >150 nm. (AFRL image)"
From: Wright Patterson Air Force Base
http://www.wpafb.af.mil/photos/mediagallery.asp?galleryID=2601&?id=-1&page=7&count=24

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Nanofiber

Introduction

Nanofibers, also commonly spelled as nanofibers, are fibers with diameters of less than 1000 nanometers (nm). There are two ways in which nanofibers are synthesized: through interfacial polymerization and electrospinning.

Electrospinning is most commonly referred, frequently yielding inorganic fibers such as titanium dioxide ($TiO2$) and aluminum dioxide ($AlO2$). The process uses an electrical charge to draw fibers from liquids.[1]Interfacial polymerization often times allows the development of organic nanofibers, but not always. A popular type of nanofiber used in scientific study, experiment, and research are carbon nanofibers (CNF). These nanofibers are graphitized by catalytic synthesis. In general, nanofibers are being used in medicine, protective clothing, filtration systems, and in antibodies against biohazardous materials and bacteria.[2]

Nanofiber Research

Research on nanofibers or research that uses nanofibers are often times divided into two categories: in the development of yarns, fabrics, and other materials to be used for coatings, and in medicine.

Yarns, Fabrics, and Coatings

The Asian Office of Aerospace Research and Development (AOARD) is investigating solutions to problems in the development of multifunctional yarns and fabrics for sensing, communication, and energy harvesting and storage. The research is three-fold. First, to study technology capable of spinning the materials. Secondly, the researchers are focusing on the degradation of nanofiber functionality when surface area decreases and finally, how loading levels and durability decrease after the yarn is coated with nanofibers.[3]

The AOARD is also looking into developing functional nanofibers for smart structures by demonstrating scalability and reproducibility of the Functional Composite Nanofiber concept using superparamagnetic nanofibers and carbon-nanotube fibers. The carbon fibers and nanofibers are being fabricated into three-dimensional structures for applications in sensing.[4]

Nanofibers, and other like nanoparticles, are also being incorporated into polymers creating composite materials to be used as replacements for aluminum structures on satellite systems because of the light weight and the low resistivity. This low resistivity is consistent with that of conductive materials. With objectives to determine ionizing and non-ionizing radiation effects on resistivity and electrostatic discharge, the researcher focused on how the materials responded to being irradiated with electrons and neutrons in a simulation of a space radiation environment. There was no change in the carbon nanofiber composite's resistivity, which suggests that the carbon nanofiber may be a suitable, if not excellent, replacement for the aluminum.[5]

Medicine

Within medical communities, nanofibers are being studied for applications in tissue engineering, and-or regeneration. Researchers at Seoul National University in Korea are studying the formation of hydrogels through nanofiber entanglement and self-assembly to use in tissue engineering and in controlled drug delivery systems. These researchers found that the nanofiber solution can mix with aqueous cells, at room temperature, and change into gels that encapsulate cells in a three-dimensional environment. The cells growing within these three-dimensional networks do not compromise cell viability and the cells can be later released through a sol-gel transition.[6]

Nanofibers are also being used in studies that are attempting to bridge the gaps between spinal cords and lumbosacral ventral roots in non-human primates, with later intentions, upon determination of success, to apply the same uses in humans to help correct nerve damage and possibly spinal-cord injuries. By acting as nerve guide conduits, the nanofibers could potentially be used to assist in neuroprotection, axonal regeneration, and functional innervation, all to restore lost or damaged motor functions.[7][8][9]Additionally, nanofibers have been studied and used as biodegradable nerve guides providing guidance and delivery to regenerating axons and Schwann cells.[10]

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Nanofilm

Introduction

Nanofilm is a small, thin film.

Nanofilms in Research

Nanofilms have previously been studied for:

- anisotropic wetting behavior. Scientists at the Naval Research Laboratory engineered a nanofilm of nanorods that demonstrated directionally-dependent wetting behavior through a pin-release droplet ratchet mechanism. [1]
- enhancing the strength of polymers to industrially-efficient levels [2]

Nanofilms have also recently been announced as crucial to regenerative endodontics. Scientists at ACS Nano, as reported by Understanding Nano, are using nanofilms tainted with alpha melanocyte stimulating hormone (alpha-MSH) to develop an alternative to root canal procedures, which removes pulp and tissue from inside a tooth but leaves the decaying, if not dead, tooth in the mouth. The new nanofilms are expected to regenerate and increase the fibroblast cells of dental pulp. [3]

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Nanohealth

Nanohealth

Nanohealth is comprised of the many different ways that nanotechnology impacts human health. Some examples are:

Nanohealth Research

Laser Technology

Using a combination of nanohealth and laser technology, surgeons are now able to perform surgery at a different location than the patient. The surgeon is able to do so by operating a camera and a laser, which performs the surgery via a computer and internet. There will be a head surgeon at the location of the patient controlling the camera. This can be used by military that are deployed with limited access to sub-specialists.[1]

Prostate Cancer Detection

The lacZ gene encoding E. coli beta-gal is used for reporting system in cancer gene therapy. The prostate-specific membrane antigen (PSMA) was identified to be the ideal antigenic target for prostate cancer. Dr. Yu developed a "new concept of the Gd(III)-based MRI contrast agents composed of three moieties:(A) a signal enhancement group… B) an Fe(III) chelating group;…(C) beta-D-galactose or glutamate."[2]

Drs. Clinthorne and Majoewski "hypothesize that a dedicated endorectal probe for positron emission tomography (PET) will provide significant improvements in image quality over conventional, external-ring PET scanners used alone."[3]

Nanotechnology and Occupational Health and Safety

The Army also provides reports "for evaluating and managing the potential life cycle risks of nanomaterials."[4]"

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Nanoindentation Hardness Tests

Introduction

"Indentation hardness tests are used to determine the hardness of a material to deformation. Several such tests exist, wherein the examined material is indented until an impression is formed; these tests can be performed on a macroscopic or microscopic scale. When testing metals, indentation hardness correlates linearly with tensile strength. This important relation permits economically important nondestructive testing of bulk metal deliveries with lightweight, even portable equipment, such as hand-held Rockwell hardness testers."[1]

Nanoindentation Hardness Tests Research

Nanoindentation hardness testing has applications in many fields including the following:

- The development of "realistic combinations of ceramics and/or semiconductors that simultaneously achieve high hardness (40 GPa) and toughness (400 MPa*m1/2)." This may be achieved through the development of "thin coatings in environments involving severe wear and/or dynamic penetration" for use in a "wide range of industrial applications, including automotive, aircraft, electronics, manufacturing, and biomedical."[2]

"Hybrid" Scanning Nanoindenter

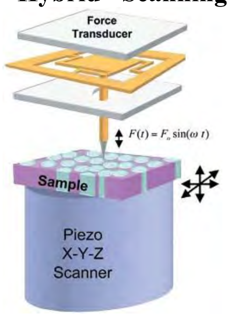

Image courtesy of: Naval Research Laboratory
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Nanolithography

Introduction

Nanolithography is the study and application of fabricating nanometer-scale structures, patterns that have at least one dimension between the size of an atom and is approximately 100 nanometers in size. Nanolithography is primarily used during the fabrication of semiconductor integrated circuits or nanoelectromechanical systems.[1]

Techniques

There are at least twelve techniques of nanolithography by which study, experimentation, and research is guided:

- Atomic force microscope
- Charged-particle
- Double-patterning
- Electron-beam direct-write
- Extreme ultraviolet
- Magnetolithography
- Maskless
- Nano-imprint
- Neutral-particle
- Optical
- Scanning probe
- X-ray

Of these techniques, the most popularly used is the scanning probe, also known as the Dip-Pen Nanolithography (DPN) technique. However, using one technique of nanolithography is not exclusive; the use of one technique often includes the use of several others. For example, using a scanning probe includes the use of direct-write and atomic force microscopes, but may also include the use of nano-imprints and double patterning.

Dip-Pen Nanolithography

DPN is a type of scanning probe nanolithography that uses a pen with a metal nib that can be dipped into ink. DPN uses an atomic force microscope to place a layer of molecules on a substrate in a manner very similar to that of a fountain pen. It allows the researcher to directly write on the substrate (hence, direct-write lithography) to generate "surface-patterned chemical functionality on the sub-100 nm length-scale." [2]This type of nanolithography is useful with both metal and dielectric substrates, often times the preferred choice when using semiconductors.[3]

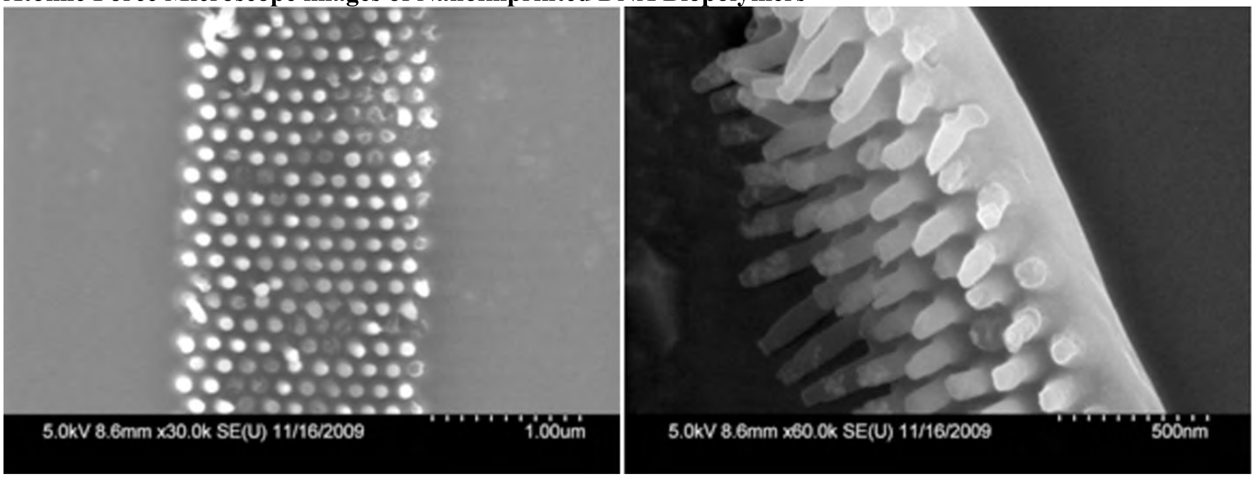
DPN uses two types of ink: molecular and liquid. A molecular ink is typically a coating of small molecules on the nip that are deposited through a water meniscus, such as a silicon-hydrogen compound written on glass, and liquid ink is any type of ink that is liquid as it is being deposited, such as DNA, proteins, and sol-gels.[4]

Nanolithography Research

Like nanoscience and nanotechnology, nanolithography is a very young discipline for academic and industrial research. As such, research on nanolithography is limited to research currently in progress.
The Asian Office of Aerospace Research and Development is combining nanolithographic techniques with synthetic and biological nanostructures in order to study fundamental recognition, assembly, charge transport, and optical coupling in living systems.[5]

The University of Illinois-Champaign utilized the nano-imprint lithographic method to produce site-controlled quantum dots with high dot intensity, uniform size distribution, and optical quality.[6]

Atomic Force Microscope images of Nanoimprinted DNA Biopolymers



From: Wright-Patterson Air Force Base
Image courtesy of the US Air Force
http://www.wpafb.af.mil/shared/media/photodb/photos/100609-F-0509T-001.jpg

Additionally, scientists at Georgia Institute of Technology have developed a new type of nanolithography by slightly modifying the current process and technique of dip-pen nanolithography to incorporate heat. Thus, they were able to create a thermochemical dip-pen nanolithography (tDPN). This new technique, operating in a manner similar to that of a soldering iron, allows for a heatable atomic force microscope tip to be coated with a solid material that, when heated, melts. The researchers found that using a tDPN enables three-dimensional nanostructures to be more easily made and more complicated because of liquid writing on hardened deposits. The tDPN also increases the range with which DPN can be used because of its ability to be used in a vacuum.[7]

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Nanomachines

Nanomachines

Nanomachines are "devices ranging in size from 0.1-10 micrometers and constructed of nanoscale or molecular components." [1]

Nanomachines Research

Carbon nanotubes have been noted for their potential as the "foundation for nanomachines". It has also been noted that "inducing relative motion and/or reducing friction between molecules is desired" for "molecular machine applications." [2]

Nanomachines

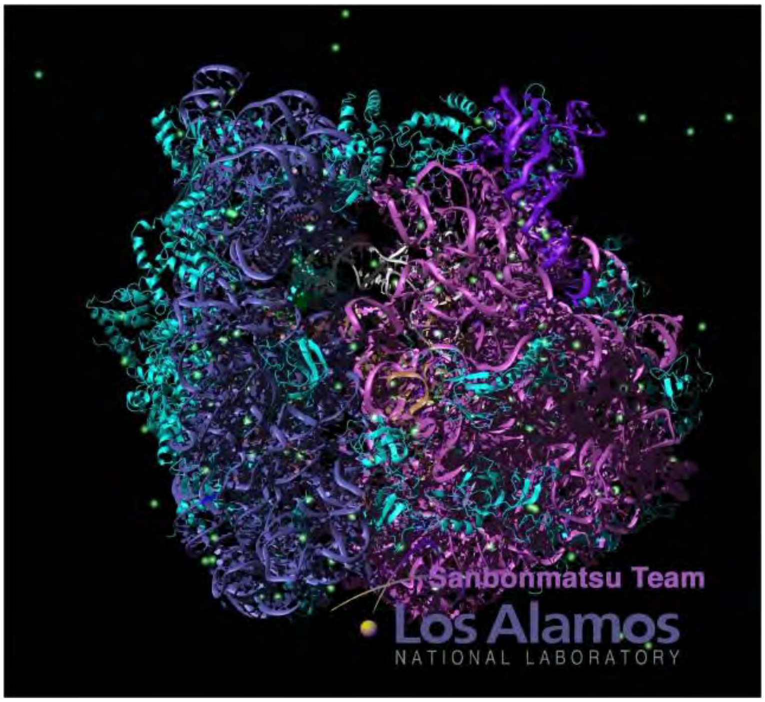

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Image courtesy of: Los Alamos National Laboratory

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Nanomanufacturing

Introduction

Nanomanufacturing is a term used to describe either the production of nanoscaled materials, which can be powders or fluids, or to describe the manufacturing of parts "bottom up" from nanoscaled materials or "top down" in smallest steps for high precision, used in several technologies such as laser ablation, etching and others. Nanomanufacturing should not be confused with molecular manufacturing, which refers specifically to the manufacture of complex, nanoscale structures by means of nonbiological mechanosynthesis (and subsequent assembly).[1]

Nanomanufacturing Research

Nanomanufacturing is becoming a mainstream technology, allowing manufacturing professionals to implement applications based on nanotechnologies, specifically materials and processes that are mature enough for use, with an emphasis on additive manufacturing processes, including micromachining, molecular manufacturing and molecular self-assembly.[2]

Moore's Law stated that the number of transistors on a microprocessor would continue to double every 18 months; out into the 2020 or 2030 timeframe. At that point in time, we would find the circuits on a microprocessor measured on an atomic scale. Thereafter, the logical next step would be to create quantum computers, which will harness the power of atoms and molecules to perform memory and processing tasks. Quantum computers have the potential to perform certain calculations significantly faster than any silicon-based computer.

Moore's Law:

On 13 April 2005, Gordon Moore stated in an interview that the law cannot be sustained indefinitely: "It can't continue forever. The nature of exponentials is that you push them out and eventually disaster happens." He also noted that transistors would eventually reach the limits of miniaturization at atomic levels.[3]

What is Nanomanufacturing?

Nanomanufacturing is about locating and manipulating individual atoms and molecules in a material. The technology can be used to create new products or increase the useful functions in existing products.
Although nanometer-size particles have been in use by industry for decades, the knowledge of the exact size, location and function of those materials increased dramatically during the 1980s and 1990s with the development of new scientific instruments and tools. Rapid advances have already included the discovery of new materials, with the promise of more in the future.

Definitions of nanomanufacturing will blur as traditional approaches to mechanical engineering, chemistry, electronics and biology are combined in new ways.

In applications of molecular manufacturing or molecular self-assembly techniques, additive processes place atoms or molecules precisely where they are needed. These molecules are engineered to have natural chemical attraction, or to be catalyzed by some energetic input, such as heat, electricity, light or enzyme.[4]

Nanotechnology RSL Partnerships in the United States, 2009

From: National Nanotechnology Coordination Officehttp://www.handle.dtic.mil/100.2/ADA540832
Image courtesy of the National Nanotechnology Coordination Office

1. A Policy Primer

Nanoscale science, engineering and technology-commonly referred to collectively as nanotechnology-is believed by many to offer extraordinary economic and societal benefits. Congress has demonstrated continuing support for nanotechnology and has directed its attention primarily to three topics that may affect the realization of this hoped for potential: federal research and development (R&D) in nanotechnology; U.S. competitiveness; and environmental, health, and safety (EHS) concerns. This report provides an overview of these topics-which are discussed in more detail in other CRS reports-and two others: nanomanufacturing and public understanding of and attitudes toward nanotechnology.[5]

2. National Nanotechnology Coordination Office, Arlington VA

This report on Regional, State, and Local (RSL) Initiatives in Nanotechnology is the result of a topical workshop convened 1-3 April 2009 in Oklahoma City, Oklahoma, by the Nanoscale Science, Engineering, and Technology (NSET) Subcommittee of the National Science and Technology Council's Committee on Technology.[6]

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Nanomaterial toxicity

Introduction

The adverse health of effects of nanomaterials is referred to as nanotoxicity or nanomaterial toxicity. Understanding the health effects of materials on the nanoscale can be quite complex. This intricacy in understanding is due to the fact that "[n]anomaterials can exhibit drastically different characteristics compared to their bulk counterparts." Due to the characteristic difference of nanomaterial the same type on the nano or bulk scale the same material on a different scale can interact with biological materials on with divergent results. "A greater understanding of the interaction of nanomaterials with biological systems, especially of the interaction of nanomaterials with cell membranes, with enable scientists to take full advantage of the unique properties of nanomaterials while minimizing their adverse effects."[1]

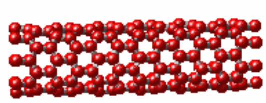
Canada is currently undertaking research into the "pulmonary and cardiovascular injury", health effects, of a variety of different nanomaterials "(e.g., nanoparticulates of zero-valent iron, gold, silver, TiO2, single walled carbon nanotubes, and C60 fullerenes)." Alternative research is being conducted on the nanomaterial effects on "reproductive, developmental and transgenerational effects; exposure and tissue penetration, interactive effects with microorganism, immune defenses and genotoxicity" [2]

For more information on: Nanohealth

Definition

Nanomaterials and nanoparticles toxicity concerns the recognition and understanding of toxicity affecting biological structures. Biological structures are effected during the production and manufacturing of nanomaterials and nanoparticles. "Among diseases associated with nanoparticles are asthma, bronchitis, lung cancer, neurodegenerative diseases (such as Parkinson`s and Alzheimer`s diseases), Cohn's disease, colon cancer. Nanoparticles that enter the circulatory system are related to occurrence of arteriosclerosis, and blood clots, arrhythmia, heart diseases, and ultimately cardiac death. We show that possible adverse effects of nanoparticles on human health depend on individual factors such as genetics and existing disease, as well as exposure, and nanoparticle chemistry, size, shape, and agglomeration state." Research is being conducted to gain further understanding into the causes and cures to nanomaterial related toxicity. In the future manufacture and disposal of nanomaterial's with be able to be adapted to result in few health related side effects. [3]

Carbon Nanotubes



From: Emerging Enviromental Issues Topic 20 June 2006
http://www.p2sustainabilitylibrary.mil/issues/emergejun2006/index.html
Image courtesy of the National Aeronautics and Space Administration
"Carbon nanotubes are one of the fundamental building blocks of nanotechnology. A nanotube is, in essence, a rolled sheet of carbon that is one atom thick. By altering the structural characteristics of these sheets of carbon and/or by the addition of layers, carbon nanotubes can be given specific attributes."[4]Research into the potential risks and health effects of widespread use carbon nanotube toxicity are still in the beginning stages.[5]

Nanomaterial Toxicity Research

Nanotoxicology

As a result of growing field of nanoscience a new field of nanotoxicology is emerging. "Research within this field is highlighting the importance of material physicochemical properties in how dose is understood, how materials are characterized in a manner that enables quantitative data interpretation and comparison, and how materials move within, interact with and are transformed by biological systems. Yet many of the substances that are the focus of current nanotoxicology studies are relatively simple materials that are at the vanguard of a new era of complex materials. Over the next fifty years, there will be a need to understand the toxicology of increasingly sophisticated materials that exhibit novel, dynamic and multifaceted functionality. If the toxicology community is to meet the challenge of ensuring the safe use of this new generation of substances, it will need to move beyond nano toxicology and towards a new toxicology of sophisticated materials." [6]

Environmental Safety and Occupation Health

Research is being conducted on the potential "health effects of nanoparticle on biological systems." Environments that simulated the human lung are being used to "evaluate respiratory toxicity of nanoenergetic materials." Scientists have already "demonstrated that there is a size dependent toxic effect of silver and silica nanoparticles, while in terms of gold nanotoxicity size, charge, and shape were mediating factors. When keratinocytes were exposed to gold nanospheres and rods, the rod shaped gold induced more toxicity. Furthermore, charged gold nanoparticles induced apoptosis, while neutral gold nanoparticles did not. Additionally, studies with nanoenergetic aluminum have demonstrated that at low levels of exposure there was little toxicity in the lung co-cultures, however, the immune cells ability to respond to bacterial pathogens was reduced. Taken together, all of these nanotoxicity studies demonstrate that there are multiple parameters that will contribute to how nanomaterials interact with a biological system. It is imperative to characterize these materials in order to fully understand the biological responses and their relationship to potential human health concerns." [7]

Footnotes

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Nanomaterials

Introduction

Nanomaterials are substances with at least one dimension between approximately 1 and 100 nanometers(nm).[1]The defining characteristic of nanomaterials is their size, not their "material." Nanomaterials can be comprised of various constituents including, but not limited to, carbon-based dendrimers (nano-sized polymers), ceramics, metals, or composites.[2]

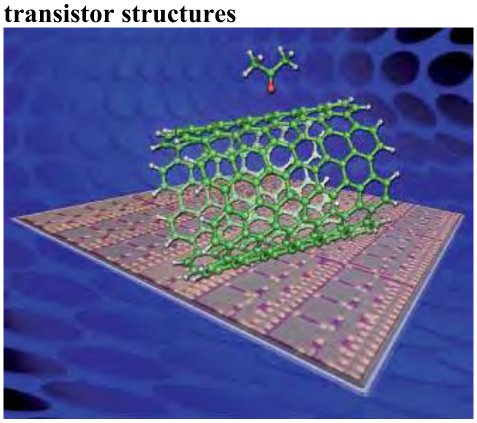
Nanomaterials Research

Research in the field nanomaterials is varied. Research is being conducted in various fields, including in health related topics such as toxicity; for example, the potential for toxicity in engineered nanomaterials in the nanobiotechnologies.[3]

Sitao V. Brownheim, at the Air Force Institute of Technology, sponsored research titled "Characterization and In Vitro Toxicity of Copper Nanoparticles (Cu-NPs) in Murine Neuroblastoma (N2A)," which examined the risks of exposure to copper nanoparticles in an industrial or military setting.[4]An additional difficulty in establishing nanotoxicology is the abundance of engineered nanomaterials.[5]Exploration into nanotoxicities advances nanobiotechnologies and aids in the production of future weapons systems.[6]

Additional studies are also being conducted on the viscoelastic properties of nanomaterials with the use of an atomic force microscope.[7]Nanomaterials have many potential uses including their "potential applications in Army vehicles, especially for improved ballistic and blast protection."[8]
Kelechi Anyogu and Nichloas A. Kotov, Nico Technologies Corp., examined how to "achieve large scale high-throughput manufacturing of multifunctional nanocomposites which are comparable in the physical characteristics to the standard aerospace composites, based on layer-by-layer (LBL) assembly process."[9]

Carbon nanomaterials: Acetone molecule and single-walled carbon nanotube over an array of nanotube transistor structures



From: [Naval Research Laboratory](http://www.nrl.navy.mil/estd/6870/6876/projArea2.php)
http://www.nrl.navy.mil/estd/6870/6876/projArea2.php
Image courtesy of the Naval Research Laboratory

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4. Brownheim, Sitao V., Characterization and In Vitro Toxicity of Copper Nanoparticles (Cu-NPs) in Murine Neuroblastoma (N2A) Cells

5. Anyaogu, Kelechi C. and Kotov, Nicholas A., Multifunctional Nanocomposite Structures via Layer-by-Layer Assembly Process
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Ma, Zheng-Dong; Sun, Ce; Cui, Yushun; Liu, Yuanyuan; Hulbert, Gregory M.; Raju, Basavaraju; and Rostam-Abadi, Farzad, Army Tank Automotive Research Development and Engineering Center, Simulation and Test of Nanocomposites for Application in the Army, January 2010, ADA532542, http://handle.dtic.mil/100.2/ADA532542.

Nanometer

Introduction

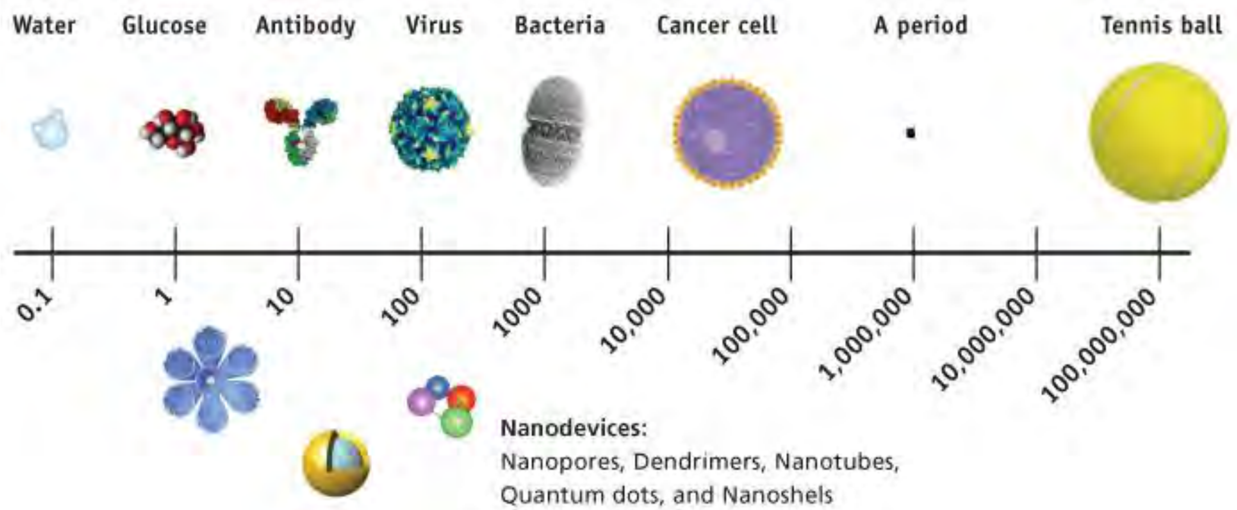
A unit of measurement that is equal to one billionth of a meter (m). Commonly referred to by the abbreviation, nm. It is most commonly used to describe the wavelength of light, however it is also used in describing nanoscience due to the tiny size of the particles.[1][2]

One nanometer is equal to $1x10^{-9}$ m or $1x10^{-3}$ micrometer (µm). In imperial measurements, one nanometer is $3.281x10^{-9}$ ft. or $39.37x10^{-9}$ in. Two nanometers, for example, is the diameter of a DNA helix while 1 nm is the length of a sucrose molecule, according to Albert Einstein. [3][4]

The science and industry communities use "nanometre," the British and SI spelling, more commonly than the American spelling, "nanometer."

Nanometers Research

Nanometer Scale



From: Food and Drug Administration Science Research
http://www.fda.gov/ScienceResearch/SpecialTopics/Nanotechnology/ucm153723.htm
Image courtesy of the National Cancer Institute

Nanometers are used primarily to refer to a particle's size. In the picture, notice that one nanometer is equivalent to the size of one glucose molecule, while one tennis ball is equivalent to one hundred million nanometers. Nanometer-sized, or sometimes nanometer-ranged, particles are being used in research for:

- studying insights into dynamics and kinetics of phase transitions [5]
- early detection and counter-measures of warfare agents used in weapons of mass destruction [6]
- immuno-nanoparticles as neuron-specific antibodies to provide more reliable drug delivery systems for therapies used in treating traumatic brain injuries (TBI) and other pathologies [7]
- developing highly reproducible lipid diffusion barriers that can be tailored to a precise location [8][9]
- reducing scattering from metal halide bullets [10]

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Nanometrology

Introduction

"Nanometrology is a subfield of metrology, concerned with the science of measurement at the nanoscale level. Nanometrology has a crucial role in order to produce nanomaterials and devices with a high degree of accuracy and reliability in nanomanufacturing." [1]

"A challenge in this field is to develop or create new measurement techniques and standards to meet the needs of next-generation advanced manufacturing, which will rely on nanometer scale materials and technologies. The needs for measurement and characterization of new sample structures and characteristics far exceed the capabilities of current measurement science. Anticipated advances in emerging U.S. nanotechnology industries will require revolutionary metrology with higher resolution and accuracy than has previously been envisioned. [1]

Another definition of Nanometrology "is the science of measurement at the nanoscale level and it has a crucial role in producing nanomaterials and devices with a high degree of accuracy and reliability in nanoscale manufacturing. Metrology of complex structures is a highly demanding application that requires extreme precision, reproducibility, and referencing to attributable standards." [2]

"Metrology instruments should be compliant with good laboratory practices, and FEI produces a comprehensive suite of charged particle microscopy tools to examine and measure materials over a wide range of lengths, from millimeters down to Ångströms in both 2D and 3D, for measuring surfaces and cross-sections to provide quantitative data on critical dimensions." [2]

An image of gold atoms on tin from a state-of-the-art scanning electron microscope

From: http://www.nist.gov/pml/div681/grp14/ngn.cfm
Image courtesy of: Physical Measurement Laboratory

Nanometrology Research

Holywell Park Loughborough University study *Characterisation* addresss "[e]ffects-based Nanometrology techniques" [3]

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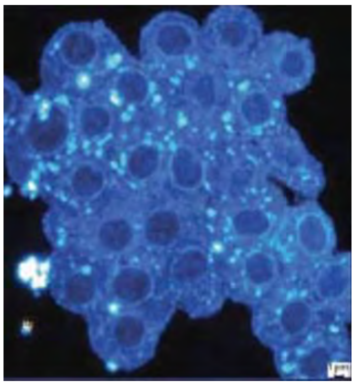
Nanoparticles

Introduction

Nanoparticles are substances which measure between 1 and 100 nanometers (nm). There are several categories of nanoparticles, each of which have different properties. Examples of nanoparticles used in biotechnology include Fullerenes, Liquid Crystals, Liposomes, Nanoshells, Quantum dots, Superparamagnetic nanoparticles, Dendrimers, and Nanorods.

Visualization of the uptake of manganese nanoparticles in cultured PC-12 cell



From: http://www.wpafb.af.mil/news/story.asp?id=123066173
Image courtesy of the US Air Force

Nanoparticle Research

In a study conducted at Leland Stanford Junior University, nanoparticles were shown to have use as "contrast agents for photoacoustic imaging". Photoacoustic imaging enables one to "estimate the change in molecular expression of various breast-cancer-specific proteins undergoing chemotherapy treatment". Further, molecular imaging agents developed using nanoparticles "allow imaging photoacoustic molecular probes at sub-nanomolar concentrations which results in the ability to image smaller tumors."[1]

In a Loyola University study, nanoparticles were used to better target radiation toward cancerous cells while lowering the radiation exposure to non-cancerous cells. This was achieved by "combining high Z nanoparticles (such as gold) with x-rays from a conventional CT scanner". Ultimately, this combination resulted in a "significant radiation dose enhancement". [2] Another approach to targeted treatment of breast cancer cells using nanoparticles demonstrates in "microwave thermal therapy". Through the enhancement of "microwave response of metallic nanoparticle contrast agents" it may be possible to heighten the "sensitivity of microwave imaging in breast cancer detection."[3]

A study conducted at Willliam Marsh Rice University endeavored to "create novel chemotherapeutic-carrying virus nanoparticles (VNPs) for localized drug delivery to breast tissue." This is accomplished by first identifying "commonalities that exits in all breast tissue" and delivering treatment specifically to those cells. The end goal is a system in which nanoparticles are used in chemotherapy as an efficient delivery system which targets only breast cells thus reducing negative side effects of treatment.[4]

One obstacle to treating cancer is interference by the immune system. A Washington State university study has worked on developing a system to effectively deliver therapeutic genes to cancer cells by using a gene carrier composed, in part, of nanoparticles. This system of delivery is accomplished by a "nanocarrier that is able to evade the immune system, circulate in the blood stream, find its target prostate cancer cells, and transfer therapeutic genes into prostate cancer cells efficiently."[5]

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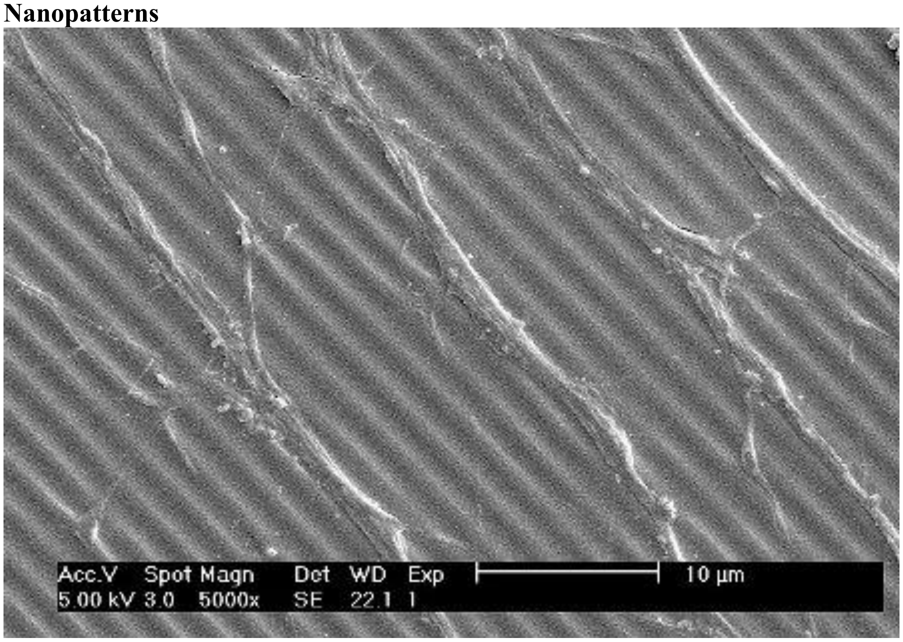
Nanopatterning

Introduction

Nanopatterning is the science and technology of fabricating defined structures on a scale of 1 to 100 nanometers (nm). These structures range from the atomic and molecular to about ¼ the wavelength of visible light. These defined structures are called nanopatterns. [1]

Nanopatterns contain minute trenches, ridges, curves and groves of nano-structured patterns and surfaces. Initially, nanopatterns were created using a technique called e-beam lithography. However, this process took a long time and only worked on smaller surfaces. A new technique has been developed that is faster and works on larger surfaces. During this new process, a patterned silicon chip is used as a stamp, and the pattern is transferred to a polymer layer by imprinting. This method allows manufacturers to replicate sub-100 nm-scale geometries on much larger areas and create nanopatterns on optical and electronic materials and biomaterials. [1]

Nanopatterns



From: **http://www.health.mil/News_And_Multimedia/News/detail/10-11-10/A_New_Approach_to_Treating_Spinal_Cord_Injury_Using_Nanotechnologies.aspx**
Image courtesy of: Military Health System

Nanopatterning Research

Nanopatterns have a very visible impact in a wide range of fields, from micronano-electronics to photonics, security, biotechnology, and medicine. One of the areas of research in which nanopatterning is being used is in electronics. Advances in nanopatterning are reducing the size of transistors in microchips, making them faster and more powerful. Some of the products that use nanopatterning, include polymer-based optical elements, organic LEDs (light-emitting diodes) and lab-on-a-chip systems.[2]

There is also a vibrant nanopatterning research community in the United States and Europe. This research community has developed new materials and tools for nanopatterning, filed several patents regarding nanopatterning, and published hundreds of research articles on nanopatterning. [3]

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Nanophotonic-Devices

Introduction

"Nanophotonic devices are combination of photonic light on the nanometer scale and silicon circuits. The vision of the Electronic and Photonic Integrated Circuits (EPIC) program is to demonstrate high performance nanophotonic devices in Si fabricated in a Complementary Metal-Oxide Semiconductor (CMOS) compatible process, and thus put photonics on its own "Moore's Law" towards the ultimate limit of wavelength-scale devices. This would enable integration of complex electronics and photonics circuits on a single Si chip, eliminating the multiple materials platforms currently used to accomplish such functionality, and provide a seamless interface between photonics and electronics. This is expected to have a revolutionary impact wherever photonics and electronics intersect." [1]

Nanophotonic Devices' Research

Nanophotonic devices are being used in research to assist with the study of nanosized structures and particles. Such devices include components such as lasers, amplifiers, isolaters, and optical switches. [2]
These devices are being used to:

- estimate time domain simulations from finite differences to discover the machining accuracy of the edge for detecting cold Rb atoms. This resulted in the development of an atom detector required for atom-manipulation experiments with near-field lights by researchers at the Tokyo Institute of Technology. [3]
- observe objects on earth and in space. Researchers at the Space Vehicles Directorate of the Air Force Research Laboratory are using the confines of a nanophotonic device's crystal material to investigate quantum and classical interference effects when a three-level system interacts with cavity field and external driving field modes. [4]

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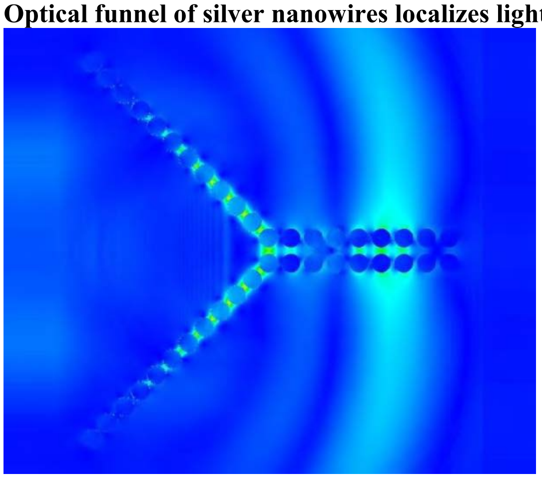
Nanophotonics

Introduction

Nanophotonics is "study of the behavior of light on the nanometer scale. It is considered as a branch of optical engineering which deals with optics, or the interaction of light with particles or substances, at deeply sub wavelength length scales."[1]

Nanophotonics Research

Optical funnel of silver nanowires localizes light on the 100 nm scale



From: http://glassblowing.anl.gov/Nanophotonics/index.html
Image courtesy of the Argonne National Laboratory

Nanophotonics has many applications in research including the following:

- "Plasmonics and metamaterials applied to new algorithm development" [2]

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Nanoplate

Introduction

A nanoplate, also referred to as nanoplatelet, is a flat nanoscopic chip-like structure.

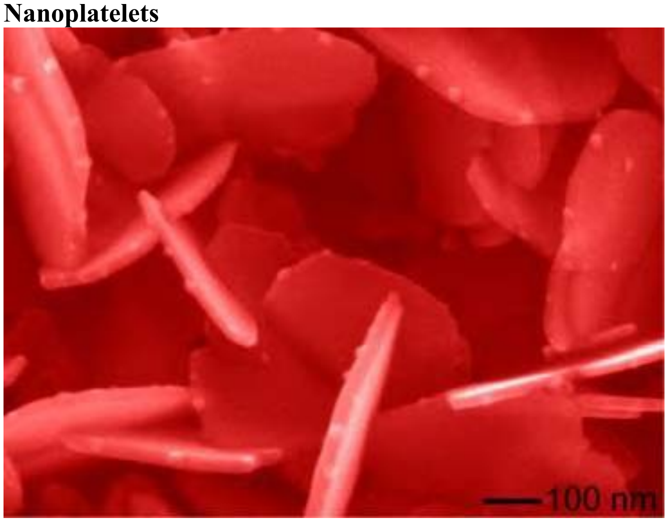
Nanoplate Research

Researchers at Clemson University in South Carolina modified silver nanoplates. They first developed a generation of silver nanoplates that were obtained by seed-mediated growth of silver particles. This new solution was aged at forty degrees Celsius, resulting in new silver nanodisks with plasmon absorption bands at 475 nanometers that can be tuned within 430 and 560 nanometers. [1]

These included algorithms for simulations of benchmark experiments and processing flows. The researchers found that nanoplatelets can be used in defect detections and tracking diagnostics. [2]
Nanoplatelet composites, primarily graphite (a carbon allotrope) composites, are frequently used in reinforcement or protection purposes because of the high modulus and strength. Their effectiveness, however, depends on surface functionalization, which includes criteria such as dispersion and interfacial bonding.

These researchers found potential applications for nanoplatelet composites in reinforcement and protection by uses in diffusion barrier films and coatings. They also found that graphite nanoplatelets in particular offer protection against electromagnetic interference and ultraviolet light. As a result, it has been proposed that graphite nanoplatelets, or nanoplatelet composites at least, are being used in new Boeing 787s. [3]

Nanoplatelets



From: http://www.anl.gov/pse/Publications/success_stories/birth_of_nanoparticles.html
Image courtesy of: Argonne National Laboratory

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Forest, M.G., University of North Carolina-Chapel Hill, High-Performance Macromolecular Materials, 28 February 2010, ADA518688, http://handle.dtic.mil/100.2/ADA518688.

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Nanoporous

Introduction

A material consisting of regular organic or inorganic framework supporting a regular, porous structure. The pores of a nanoporous substance are in the nanometer (nm) range, between 1×10^{-7} and 0.2×10^{-9} meters. [1]

Nanoporous Materials Research

Nanoporous materials are being used in research to:

- develop spectrometer-based readers encoded with authentication data within the optical reflexivity spectrum and attached to tablet medication to authenticate tablet identity in anti-counterfeiting measures [2]
- develop polymers encapsulating chemotherapy drugs to be locally deposited near cancer tumors and monitored in real-time [3]

A Nanoporous Solid

From: Berkeley Lab
http://www.lbl.gov/Science-Articles/Archive/sabl/2005/August/01-hydrogen-future.html
Image courtesy of the Lawrence Berkeley National Laboratory

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Nanorods

Introduction

Nanorods are usually produced by a direct chemical synthesis from metals or semiconductors.[1] The use of nanorods in scientific and technological fields is diverse and wide-ranging, from use in display technologies, in which their reflectivity can be changed through orientation to electric fields, to microelectromechanical systems, in which the nanorod can be used to generate the electricity for driving such devices. [2][3]Nanorods are also being applied as light-propagation tools for tunable optoelectronic devices like lasers, detectors, and photovoltaics. [4]

Nanorods Research

Recent research, however, has focused on the use of nanorods to enhance behaviors of laser and optics. An experimental study by G.A. Wurtz and et al found that the nonlocal optical behavior of plasmonic nanorod metamaterials enabled an enhanced optical response as a result of the strong coupling between nanorods.[5]

Another study, though, found that intervalley splitting does not affect the photoluminescence; J.G. Tishler et al at the Naval Research Laboratory used circularly polarized magnetophotoluminscence and optically detected magnetic resonance spectroscopies to study nanorods in a singlet-triplet state, finding that in the triplet state, there is unusual optic activity but the bright singlet state is not populated at low temperatures.[6]

Nanorods are also instrumental to study of optics because they allow for the tunability of plasmonic resonances to occur over a wide range on the optical spectrum, from visible wavelengths to infrareds and enables engineering of the plasmonic excitation.

Use of Nanorods in Medicine

The use of nanorods is being explored in enhancing microwave sensitivity to detect breast cancer and as a platform to detect and differentiate strains of pneumonia in culture and throat swab samples. For more information on nanotechnology in health or biology, see NanoHealth. [7][8]

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Nanoscale

Introduction

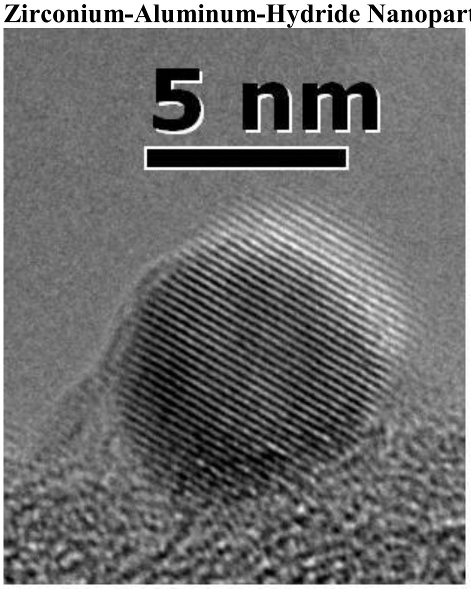
Nanoscale or nanoscopic scale refers to structures occurring or within the dimensions of nanometers, with in a range of 1-100 nanometer range.[1][2][3]

Nanoscale Research

Nano and Quantum Wire

There is a great deal of diversity in applications of materials produced on the nanoscale. For example, nanowires have potential use in "nanoscale electronics, photonics, thermoelectric, biotechnology, and energy conversion."[4]Additionally, "quantum wires made of components with at least one dimension being at nanoscale show great potential for future optoelectronic device applications. The elastic fields in quantum structures affect their physical and mechanical properties, and also play a significant role in their fabrication." [5]

Zirconium-Aluminum-Hydride Nanoparticles



From: Naval Research Laboratory
http://www.nrl.navy.mil/techtransfer/fs.php?fs_id=ENE02
Image courtesy of the Naval Research Laboratory

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2. http://www.merriam-webster.com/dictionary/nanoscale
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Nanosensor

Introduction

A nanosensor is a biological, chemical, or surgical sensory point being used to deliver information about nanoparticles. They are used medicinally to identify cells a particular body may need by measuring changes in, among others, cell volume and temperature, to distinguish between types of cells at the molecular level.

A type of nanosensor used in medicine is the cadmium selenide quantum dots, whose fluorescence allows a doctor to see the location of tumor or cancer cells. However, cadmium selenide is highly toxic and consumption of large amounts, even as nanoscopic as a quantum dot, could be fatal. [1]

Nanosensor Research

Use of Nanosensors in Detection

In this project, the investigator is building and optimizing flexible, easy to operate, highly sensitive detecting devices that will be able to quantify serum protein concentration and monitor changes of biomarker concentration. The investigator intends to use three different serum biomarkers that, most importantly, have commercially-available antibodies. At the project's end, the researchers will determine if the biomarkers can detect ovarian cancer recurrence. If successful, the developed sensors could be used as a tool for early detection of ovarian cancer prior to relapse. [2]

Researchers at Purdue University used nanotechnology with visual microscopic techniques, Surface-Enhanced Raman Spectroscopy (SERS), to determine and watch for kinase protein reactions in living cells to detect beginning cancerous growth. SERS was used for its ability to see changes in molecular properties by attaching the studied molecules to metal surfaces. The researchers made metal nanoparticles attach with kinase interacting molecules on their surfaces. [3]

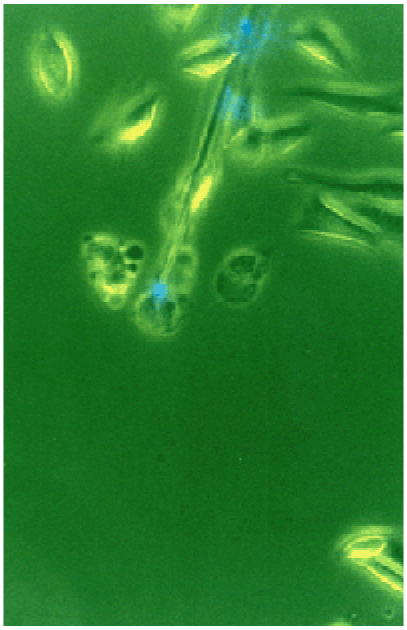
Partnering researchers at three universities are working to better understand the phenotypes for autism and other central nervous system development alterations. Their study is comprised of three different projects. First, to better understand implications of abnormalities associated with autism or autism spectrum disorders (ASD), potential for a biomarker, and if targeted treatment will reverse alterations in immune cells. Second, to identify consequences of abnormalities and alterations of ASD, and the third project aims to improve detection of the abnormalities to enable easier and more cost-efficient analysis. The researchers used a chip composed of an artificial network of nansensors to determine the vulnerabilities and monitor resulting cellular stress. [4] [5] [6]

Use of Nanosensors in Protection and Technology

At Oceanit, a science and engineering company based in Honolulu, Hawaii, researchers are developing a blast dosimeter system to integrate in existing combat helmets. The sensor will have no substantial effect on the equipment profile, nor will it impact the soldier's duties. Integrating the sensor properties with computational modeling will allow the blast to be recorded and then correlated with data from anticipated pressure and forces experienced by the brain and other cranial tissues. This will establish a scoring methodology to rate the explosive type and the blast trajectory and intensity to help determine injuries to the brain and aid early treatment of brain injuries. [7]

At the Lawrence Livermore National Laboratory, researchers are attempting to develop battery less chemical and-or biological detection devices; that is, sensors without an external power source. The researchers proposed that nanosensors requiring small power can be harvested from the environment. As such, the first generation of new battery less sensors was developed with nanowires and used ethanol solvent as a testing agent. [8]

Nanosensors



From: http://www.ornl.gov/info/ornlreview/rev32_3/nanosens.htm
Image courtesy of: Oak Ridge National Laboratory

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Nanoshells

Introduction

A nanoshell is a spherical nanoparticle with a dielectric core covered by a thin metallic shell. The shell is usually gold. Nanoshells typically also involve plasmon, or collective excitation, where electrons oscillate simultaneously. [1]

Nanoshell Research

Nanoshells have a diverse range of applications. They are, however, primarily being used in cancer research. Nanoshells are used to:

- target breast cancer cells and use localized heat to destroy cancer cells in gene therapy [2]
- develop controlled electromagnetic environments to study photophysical processes [3]
- detect cancer cells because of the nanoshell's ability to bind to surface of tumor cells overexpressing tumor antigens [4]
- immobilize whole cells for production of bioactive molecules [5]

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Nanostructure Powder

Introduction

Nanostructure powder is a powder of nanostructures that have been reduced to a fine powder through methods such as grinding, pounding, milling, and abrasion.

Nanostructure Powder Research

Nanostructure powder is being studied to determine many different formations and aspects of nanoscience. Some of the research about nanostructure powders includes:

- the understanding of properties. Researchers at the University of Missouri have synthesized nanostructures by using parameters such as current, voltage, catalysis, and gas pressure. The resulting properties (structural, morphological, and vibrational) were investigated by using, among many other devices, x-ray diffraction, transmission electron microscopy, and scanning electron microscopy. [1]
- the use of nanostructure powders in development of thermal spraying coatings for use in thermal barrier coatings for turbine blades and wear-resistant rotating parts. [2]
- the preparation and physiochemical process of developing nanostructured powder to yield high performance in application-usage. [3]

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Nanostructure

Introduction

A nanostructure is an extremely small device, material, or particle. Nanostructures have a physical dimension smaller than 100 nanometers, ranging from clusters of atoms to dimensional layers. Nanostructured materials are modulated over nanometer length scales in zero to three dimensions. They can be assembled with modulation dimensionalities of zero (atoms clusters or filaments), one (multilayers), two (ultrafine-grained overlayers or coatings or buried layers), and three (nanophase materials), or with intermediate dimensionalities.

Examples of nanostructures are nanoparticles, nanorods, quantum dots. [1]

Nanostructure Research

The areas of research in which nanostructures are being used:

- Research in nanostructures has led to the development of high performance rechargeable batteries with an ultrafast recharge rate. [2]
- Nanostructures are also being used in the development of cost-effective nanostructure solar cells. [3]
- Cheminformatics methods such as quantitative structure-activity relationship (QSAR) modeling [4]
- Germanium nanowire [5]
- Sputter-Deposited Molybdenum Disulfide (MoS2) Films [6

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Nanotubes

Introduction

A nanotube is considered to be one of the largest nanomaterials with a length to diameter ratio of 132,000,000:1 nanometer (nm). Nanotubes belong to the fullerene structural family within nanoparticles and have ends capped with the hemisphere of buckyball structures. Nanotubes have a bonding process very similar to that of graphite and naturally align into ropes by van der Waals force.[1]
A nanotube may refer to one of four types: inorganic nanotube, DNA nanotube, membrane nanotube, or carbon nanotube.[2]

Types of Nanotubes

Inorganic nanotubes are typically made with metal oxides, some of which occur naturally in mineral deposits, and are strongest under compression, making them suitable for body armor such as bulletproof vests, and are being considered for use as lubricants in the automotive industry.[3]DNA nanotubes are very similar to Carbon nanotubes. They are mostly hollow and are the result of DNA self-assembly. Thus, DNA nanotubes are easily modifiable and can connect more easily to other structures.[4]

Membrane nanotubes exist in animal cells, allowing for intercellular communication, such as transmitting nutrients. Conversely, membrane nanotubes can also aid the spread and development of pathologies.[5]

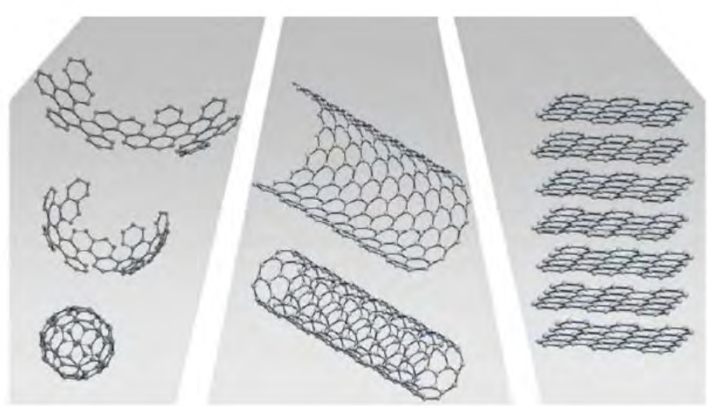
Carbon nanotubes are the most utilized and studied of the four types. They have a diverse range of applications, which include nanotechnology, body armor, material science, and architecture.[6]

Nanotubes Research

Carbon Nanotubes in Spaceflight

Carbon nanotubes, as earlier mentioned, are the most utilized and studied type of nanotubes. As such, the range of applications is widely diverse and variable. One of the more recent ways in which carbon nanotubes are being investigated is to aid further development in space exploration. Carbon nanotubes are being studied for their conductivity, which allows for an increased resistivity to radiation. This will allow the lightweight carbon nanotube, as a composite, to potentially replace the aluminum structures currently on satellites.[7]

Carbon Nanotube



From: Duncan, Nickolas A., Changes to Electrical Conductivity in Irradiated Carbon Nanocomposites, 24 March 2011. http://www.handle.dtic.mil/100.2/ADA538771
Image courtesy of the Air Force Institute of Technology

Carbon Nanotubes as Electrical Networks

Part of the research into carbon nanotubes focuses on the electronic properties.[8]In fact, these electronic properties allow carbon nanotubes, when grown on carbon or glass fibers, to be utilized as electrical networks that yield new energy storage devices that can produce approximately 100 times more power than current batteries or fuel cells alone.[9][10]

Such research and studies into carbon nanotubes have found that single-walled carbon nanotubes, carbon nanotubes with only one layer, can be used to fabricate supercapacitors. [11]

Carbon Nanotubes as Yarn

This yarn efficiently improved properties of polymeric composites, while still maintaining the polymeric transparency. The new matrix is being used to create windows, or as a laminate layer for windows, that are blast-resistant.[12]

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Nanowires

Introduction

Nanowires are small structures with diameters **10 $^{-9}$** or $^{1}/_{1,000,000,000}$ meters. Nanowires are so small that instances of quantum mechanical phenomena can affect them. It is from this fact that they were coined, "quantum wires." [1]

Nanowires have some peculiar electrical properties due to their size. Unlike carbon nanotubes, whose motion of electrons can fall under the regime of ballistic transport (or flow freely between electrodes). Their conductivity is highly encouraged by the effects of their edges. These effects are a result of atoms found on the surface that are not completely bonded to neighboring atoms, as are the atoms found within the bulk of the nanowire. This disparity in connectivity forms a defect at the edge of the nanowire, and may result in a reduced conductivity at that juncture, as opposed to the middle of the nanowire. Consequently, these edge effects become more frequent and more of consequence in smaller and smaller nanowires.

The nanowires could be used, in the near future, to link tiny components into extremely small circuits. Using nanotechnology, such components could be created out of chemical compounds. [2]

Nanowires Research

Semiconductor nanowires are micro objects recently receiving major attention. Due to their unique physics they have been proposed as the building blocks for various technology applications. They are ideal for use in sensor applications with high sensitivity to the environment due to their miniaturized dimensions and high surface area to volume aspect ratio. In addition, they demonstrate ease in assembly on just about any substrate. Nanowires demonstrate flexibility with regard to carrier mobility and have become suitable for various high performance electronic applications. Current challenges involve combining and incorporating two functional nanowire elements together to form a complete nanowire circuit. [3]

Moore’s Law:
Moore's Law stated that the number of transistors on a microprocessor would continue to double every 18 months; out into the 2020 or 2030 timeframe. At that point in time, we would find the circuits on a microprocessor measured on an atomic scale. Thereafter, the logical next step would be to create quantum computers, which will harness the power of atoms and molecules to perform memory and processing tasks. Quantum computers have the potential to perform certain calculations significantly faster than any silicon-based computer.

On 13 April 2005, Gordon Moore stated in an interview that the law cannot be sustained indefinitely: "It can't continue forever. The nature of exponentials is that you push them out and eventually disaster happens." He also noted that transistors would eventually reach the limits of miniaturization at atomic levels. [4]

Practical Nanowire Application?

Nanostructures, such as carbon nanotubes and nanowires, have emerged as potential building blocks in nanoscale applications of microscopy tips 1, gas sensors 2, nanoscale interconnects 3, and field emitters 4 mainly because of their tiny size satisfying the needs of down-scale schemes, efficiently and effectively. [5]

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Plasmonic Nanolithography

Introduction

"Plasmonic nanolithography is a nanolithographic process that may enable a new generation of microchip technology. Plasmonic lithography can potentially cost much less than current lithographic techniques." [1]

Plasmonic Nanolithography Research

In order to obtain "a practical means of optical imaging, optical sensing, and nanolithography at a resolution below the diffraction limit of the light," near field scanning optical microscopy (NSOM) may be used. One study seeks a resolution to the problem of "strong attenuation of the light transmitted through the sub wavelength aperture" in NSOM through the "development of plasmonic near field scanning optical microscope with an efficient near field focusing." [2]

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Properties of States of Nanoscience

Introduction

"Quantum tunneling is in the domain of quantum mechanics, the study of what happens at the quantum scale. This process cannot be directly perceived, so much of its understanding is shaped by the macroscopic world, which classical mechanics can adequately explain. Particles in that realm are understood to travel between potential barriers as a ball rolls over a hill; if the ball does not have enough energy to surmount the hill, it comes back down. The two forms of mechanics differ in their treatment of this scenario. Classical mechanics predicts that particles that do not have enough energy to classically surmount a barrier will not be able to reach the other side. In quantum mechanics, these particles can, with a very small probability, tunnel to the other side, thus crossing the barrier." [1]

"Superparamagnetism is a form of magnetism, which appears in small ferromagnetic or ferrimagnetic nanoparticles. In sufficiently small nanoparticles, magnetization can randomly flip direction under the influence of temperature. The typical time between two flips is called the Néel relaxation time. In the absence of external magnetic field, when the time used to measure the magnetization of the nanoparticles is much longer than the *Néel relaxation time*, their magnetization appears to be in average zero: they are said to be in the superparamagnetic state. In this state, an external magnetic field is able to magnetize the nanoparticles, similarly to a paramagnet. However, their magnetic susceptibility is much larger than the one of paramagnets." [2]

"Giant magnetoresistance (GMR) is a quantum mechanical magnetoresistance effect observed in thin film structures composed of alternating ferromagnetic and nonmagnetic layers. The 2007 Nobel Prize in physics was awarded to Albert Fert and Peter Grünberg for the discovery of GMR." [3]

Thermophoresis, a "phenomenon which is observed at the scale of one millimeter or less", occurs "when a mixture of two or more types of motile particles (particles able to move) is subjected to the force of a temperature gradient and the different types of particles respond to it differently." [4]

Properties of Nanoscience research

Magnetic

Magnetic quantum tunneling

Florida State University's is researching "high frequency electron paramagnetic resonance (EPR) investigations of a series of high spin (total spin up to S = 10) manganese and nickel complexes which have been shown to exhibit single molecule magnetism, including low temperature (below 1K) hysteresis loops and resonant magnetic quantum tunneling." [5]

Superparamagnetic

The objective of the Pennsylvania University Philadelphia, "proposed research is to develop a novel approach to image mRNA transcripts via magnetic resonance (MR). Specifically, nucleic acids will be detected by taking advantage of the change in MR contrast that results when two or more superparamagnetic nanoparticles (NPs) are brought into close proximity." [6] "

Vanderbilt University is taking innovative approach to its research "in the design, synthesis, and performance characterization of clustered iron oxide nanoparticles and the use of programmed disassembly for active MR contrast enhancement. The proposed active contrast agent would be composed of superparamagnetic iron oxide nanoparticles clustered in a degradable matrix." [7]

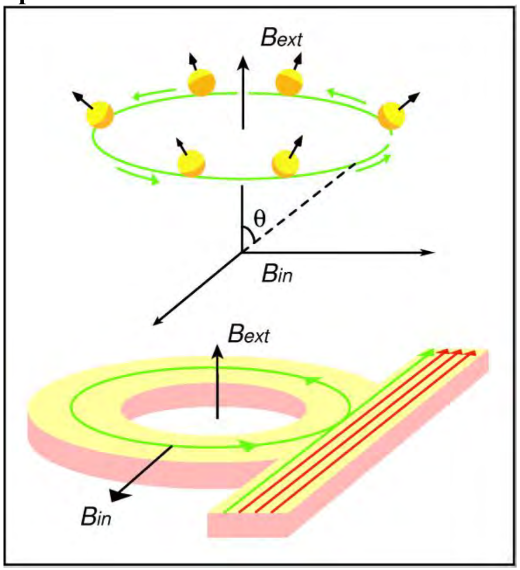
The Asian Office of Aerospace and Development is researching "the potential of developing functional composite nanofibers for components of smart structures. This overall aim of this study is to demonstrate the scalability and reproducibility of the Functional Composite Nanofiber (FNCF) concept using superparamagnetic nanofiber and carbon-nanotube nanofibers as examples." [8]

Physical

Nanoparticle transport

"Realistically molecular scattering always lies between the two limiting scattering models. Similar to the treatment of nanoparticle transport, a parameter may be introduced here to give a mixed scattering model." [9]

Spintronics



"Quantum-mechanical transport effects become important in the operation of nanoscale devices. Understanding quantum phenomena, such as tunneling and phase coherent wave-like transport, not only provides better description of device characteristics, but also paves the foundation for novel class of devices. The electron spin, a purely quantum mechanical quantity, offers an independent degree of freedom in contrast to the electronic charge. By exploiting spin we can potentially surpass the existing downscaling limitations and generate new opportunities for making ultra-dense, high-speed, low-power computing and memory devices. Spin-electronics ("spintronics") research is already accelerating the development of quantum computing, quantum cryptography, molecular electronics and sensors. While existing semiconductor devices operate in the diffusive transport regime where scattering results in heat dissipation and limits frequency response, spin transport in the ballistic regime offers opportunities which are as yet unexplored and unexploited."
From: http://www.nrl.navy.mil/estd/6870/6877/spintronics.php
Image courtesy of: Naval Research Laboratory

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Protein Biosynthesis

Introduction

"Protein synthesis is the process in which cells build proteins. The term is sometimes used to refer only to protein translation but more often it refers to a multi-step process, beginning with amino acid synthesis and transcription of nuclear DNA into messenger RNA, which is then used as input to translation." [1]

Protein Biosynthesis Research

Protein Biosynthesis is studied in the context of a wide array of subject areas including the following:

- The identification of "which mRNAs are translationally regulated by hamartin and tuberin and how the presence of nutrients or growth factors impacts this." [2]

Footnotes

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Pulsed Laser Deposition

Introduction

"Pulsed Laser Deposition (PLD) is a thin film deposition (specifically a physical vapor deposition, PVD) technique where a high power pulsed laser beam is focused inside a vacuum chamber to strike a target of the material that is to be deposited." The process for PLD is divided into four steps:

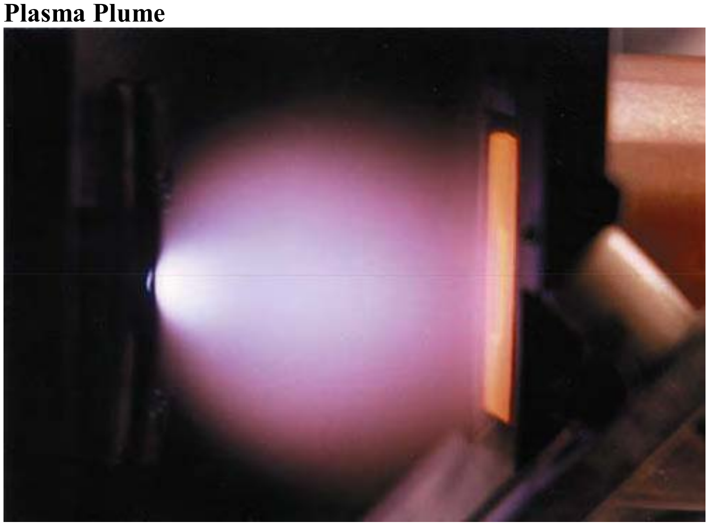
- "Laser ablation of the target material and creation of a plasma"
- "Dynamic of the plasma"
- "Deposition of the ablation material on the substrate"
- "Nucleation and growth of the film on the substrate surface" [1]

Pulsed Laser Deposition Research

The areas of research that PLD are being used:

- "HfO2 thin films comparing atomic layer deposition (ALD) and pulsed laser deposition (PLD)" [2]
- "Controlled synthesis of carbon-rich hafnia" [3]
- "Ill-Nitride based optoelectronics" [4]

Plasma Plume



Typical plasma plume generated during the PLD process
From: http://www.nrl.navy.mil/techtransfer/fs.php?fs_id=MAT19]
Image courtesy of: Technology Transfer Office

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Quantum Computing

Introduction

Quantum computing, conducted by quantum computers, is when a computer uses quantum mechanical phenomena like superposition and entanglement in order to perform operations. This differs from classical computing in which bits are used. In basic computing, the computer recognizes the bits 0 or 1 only, thus sequencing and all computations results in codes of 0 or 1. Quantum computing uses qubits similar to bits--recognizing 0 or 1. However, a qubit can also exist simultaneously as 0 and 1.[1]

Quantum computing is still in its infancy, ergo it is still primarily theoretical and applicable to theoretical physics. However, there have been recent successful experiments in using quantum computing to enhance and aid national security by cryptanalysis. There have also been developments in creating technology to be used for quantum computing, resulting in the use of nuclear magnetic resonance (NMR) technology.

Current institutions studying and exploring applications of quantum computing, or particular apsects of the field, include Los Alamos National Laboratory, Massachusetts Institute of Technology (MIT), California Institute of Technology (CalTech), and Microsoft.[2]

Models used in Quantum Computing

There are four main practical models of quantum computing:[3]

- **quantum gate array**, when the computer uses reversible circuits operating on qubits and represented by matrices [4]
- **one-way quantum computer**, which uses one qubit measurements applied to highly entangled initial states, or cluster states
- **adiabatic quantum computer**, which measures the slow continuous transformation of the total energy
- **topological quantum computer**, which braids particles into two-dimensional lattices

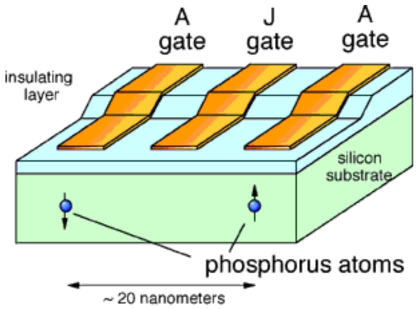
Quantum Computing Research

As the field becomes less theoretical with the development of new and advanced technologies, researchers and scientists are using quantum computing in a diverse range of applications.
At the University of Michigan, quantum computing is being used to develop mathematical and algorithmic concepts to aid the simulation of quantum circuits with error correction. The researchers have developed circuit simulations requiring universal circuits when errors occur. They have also been able to restructure and simplify the simulated circuits by extracting common functions upon completion of the circuits without error. [5]

The Air Force used quantum computations to develop a model for rate coefficients related to vibration translation transitions, basing the computations on the forced harmonic oscillator theory. This model provides rate coefficients in the high temperature regime, and is implemented to study "a one-dimensional nonequilibrium inviscid N2 flow behind a plane shock by considering a state-to-state approach." The quantum computations, or "multiquantum processes," influenced the vibrations, however the researchers found that the effective number of transitions decreased inversely according to the quantum number. [6]

Researchers at Florida Atlantic University are investigating potential strengths and weaknesses of using qudits (which are three or more dimensional-state spaces) for optical quantum computing. They are designing, developing, and simulating quantum gates that are encoding information in higher dimensional state spaces beyond the typical two-dimension polarized states. Using qudits would allow for "faster optimization of complex AF anticipatory C2I systems/database searches, high-speed signal and image processing, and faster data fusion." [7]

Proposed Quantum Computer Architecture



One proposed quantum computer architecture
From: Los Alamos Research Laboratory
Image courtesy of the Los Alamos National Laboratory
http://www.lanl.gov/mst/nano/computing.html

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Quantum Confinement

Introduction

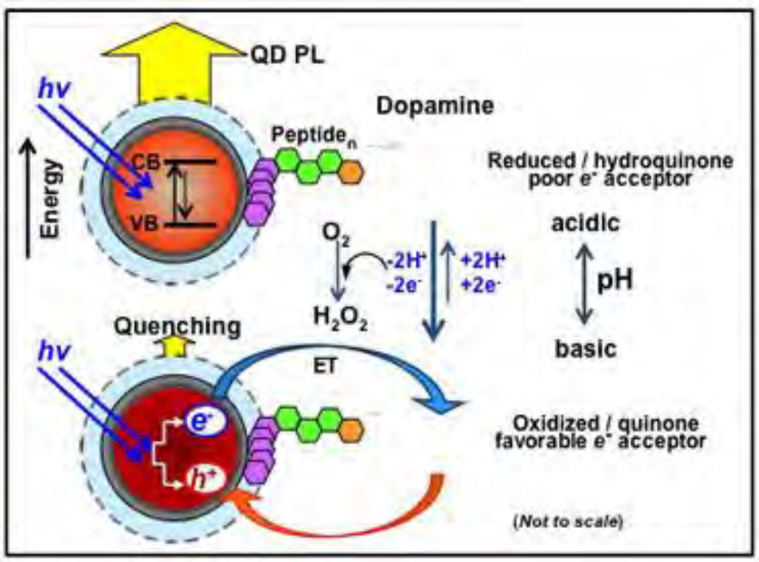
Quantum confinement occurs in particles when “the diameter of the particle is of the same magnitude as the wavelength of the electron wave function”. When this occurs, the “optical properties deviate substantially from those of bulk materials” . [1]

In semiconductors, “an electron-hole pair is typically bound within a characteristic length called the Bohr exciton radius. If the electron and hole are constrained further, then the semiconductor's properties change. This effect is a form of quantum confinement, and it is a key feature in many emerging electronic structures.” [2]

Quantum dots and quantum wells are both forms of quantum confinement. Quantum dots are a type of semiconductor “whose excitons are confined in all three spatial dimensions.” This results in quantum dots possessing “properties that are between those of bulk semiconductors and those of discrete molecules.” [2]

Quantum wells are potential wells which confine particles “which were originally free to move in three dimensions, to two dimensions, forcing them to occupy a planar region.” Quantum confinements in quantum wells occur “when the quantum well thickness becomes comparable at the de Broglie wavelength of the carriers (generally electrons and holes), leading to energy levels called ‘energy subbands’, i.e., the carriers can only have discrete energy values." [3]

Quantum dot-dopamine energy transfer mechanism



From: http://www.nrl.navy.mil/media/news-releases/110-10r/
Image courtesy of the Naval Research Laboratory

Quantum Confinement Research

Prostate cancer research has also made use of quantum confinement. A 2005 study conducted at the University of South Florida aimed “to develop and test new serum biomarkers for early detection of prostate cancer”. These biomarkers where able to “be detected at extremely low levels in blood serum through biochemical conjugation to photoluminescent nanoparticles called quantum dots (qds).” The biomarkers were believed to “realize a quantum confinement effect of electron/hole pairs, which dramatically improve[s] the luminescence quantum efficiency and offer[s] the possibility of tuning of the luminescence wavelength (color) in a broad spectral range by changing the size of the individual quantum dot.” The goal was to use multiple sizes of quantum dots to “provide a source for multiplexed optical coding of protein, lipid, or dna markers for early detection” producing a screening process which is able to detect “sub-ELISA [Enzyme-linked immunosorbent assay] levels of proteins.”[4]

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Quantum Dot

Introduction

A quantum dot is matter constrained in all three aspects of motion and dimensions. Quantum dots are a kind of semiconductor. The dimensions and shape of individual crystal are connected to the semiconductors electronic characteristics.[1][2]Quantum dots and quantum wells are both forms of quantum confinement.[3]

Quantum Dot Research

Research published in April of 2011 investigated the possible applications for "ultralow-threshold electrically pumped quantum dot photonic-crystal nanocavity laser." [4]

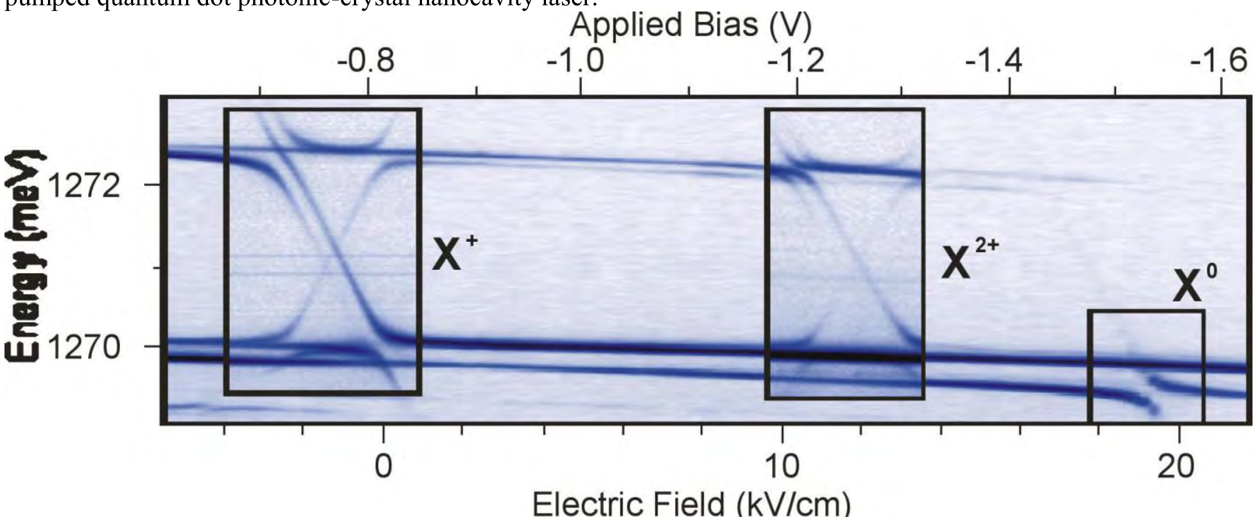

Image courtesy of the Naval Research Laboratory

"We have an extensive research effort to explore and develop quantum dot materials for quantum information science and technology. This program encompasses MBE growth, fabrication, optical spectroscopy, and coherent optical control. The materials are based on self-assembled InAs quantum dots on GaAs. Nucleation techniques are used to grow ordered quantum dot molecules. The dots are embedded in Schottky diode heterostructures so that individual carriers can be injected and coherent tunneling of carriers between quantum dots can be controlled. Both electrons and holes are of interest for spin qubits in quantum dots. Photoluminescence spectroscopy is used to characterize the optical spectra, and direct absorption spectroscopy with continuous and pulsed lasers is used to carry quantum operations, such as spin initialization, spin-preserving measurement, and quantum gates on one or two spin qubits."[5]

This type of laser has various possible applications in the fields of information technology, information processing and optical interconnects[6] At present the finest "edge-emitting and vertical --cavity surface emitting lasers have thresholds on the order of 100mA."[7]The edge-emitting and vertical --cavity surface emitting lasers dissipate so much power to be feasible for some applications. [8]

The state of the art low-threshold lasers are more practical applications for optical interconnects. In order for low-threshold laser to be used in many different applications "techniques to electrically pump these structured must be developed." A "quantum-dot photonic-crystal nanocavity laser in gallium arsenide pumped by lateral p-i-n junction formed by ion implantation" was observed to have "the lowest threshold ever observed in any time of electrically pumped laser."[9]

The field of biology is interested in the applications of quantum dots (QDs) and metal nanoparticle (NPs) due to their collective use in fluorescent labels and sensors.[10]NPs can be used to "identifying target DNA through a linker."[11]Research sponsored by the Army Research Lab Aberdeen Proving Ground Maryland was conducted to determine how NPs interact with DNA.[12]

An additional study has been conducted by the Army Research Lab Weapons and Materials Research Directorate, to examine Bacteriorhodopsin an opto-electric protein in "the membrane of the extremophile bacterium Halobacterium salinarum."[13]
The research shows that "Bacteriorhodopsin strongly absorbs light near the 570-nm wavelength, but its photoelectric activity is now shown to increase by at least 35% when integrated with ultraviolet (UV)-scavenging quantum dots."[14]

In a National Chiao Tung University Hsinchu (Taiwan) Department of Materials Science, sponsored project the object was "to improve the electron transport properties of lead selenide quantum dots and cadmium selenide terapods."[15]

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Quantum Effect

Introduction

The study of quantum effects fall largely under quantum mechanics, or quantum physics. An example of a quantum effect would be solubility. Gold is an insoluble element, however at nanoscopic range, gold becomes soluble. This transformation and changing property is a quantum effect.

Quantum effects, also referred to as quantum size effects, are the resulting "unusual properties of extremely small crystals arising from confinement of electrons to small regions of space in one, two, or three dimensions." [1]Like solubility, another property that may cause quantum effects is superfluidity, when matter behaves like fluid by flowing with neither friction nor velocity, with infinite thermal conductivity. [2]

Studying quantum effects involves the quantum realm, which is the physics scale in which the quantum effects become significant. The quantum realm begins when an object or particle is 100 nanometers (nm) or less. [3]This also places the particle within the field(s) of nanoscience and-or nanotechnology.
Applications that use quantum effects include lasers, transistors and diodes, microchips, electron microscopes, and magnetic resonance imaging.[4]

Quantum Effect Research

Although there are no specific studies focusing exclusively on quantum effects, quantum effects are noted in research reports and summaries as a byproduct of the conducted experiment or study.

Quantum effects have been noted in a study conducted by Harvard researchers. In an attempt to design a new laser customized for critical sensing applications, the researchers used molecular fingerprints that would enable the laser to detect trace amounts of explosives, chemical agents, and drugs. By tweaking the laser to use the effects produced by quantum particles comprising the laser, the researchers were able to remotely detect large groups of compounds with high sensibility, yielding a high performance in power and operating temperatures. The researchers found that the laser was successful in detecting surface-adsorbed explosives at distances up to twenty meters away and with high sensitivity. [5]

Another study looking at quantum effects used ultracold molecules. Researchers at the Institute for Quantum Optics and Quantum Information are focusing on understanding and exploiting electric, magnetic, and electromagnetic field control of weakly and strongly bound states of ultracold molecules. The researchers are using control features of these systems to produce and characterize new phases of quantum matter and expect their quantum information studies to support Department of Defense initiatives in advanced computing, chemical synthesis, and sensing technology. [6]

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Quantum Wells

Introduction

Quantum wells are potential wells which confine particles “which were originally free to move in three dimensions, to two dimensions, forcing them to occupy a planar region.” Quantum confinements in quantum wells occurs “when the quantum well thickness becomes comparable at the de Broglie wavelength of the carriers (generally electrons and holes), leading to energy levels called ‘energy subbands’, i.e., the carriers can only have discrete energy values.[1]

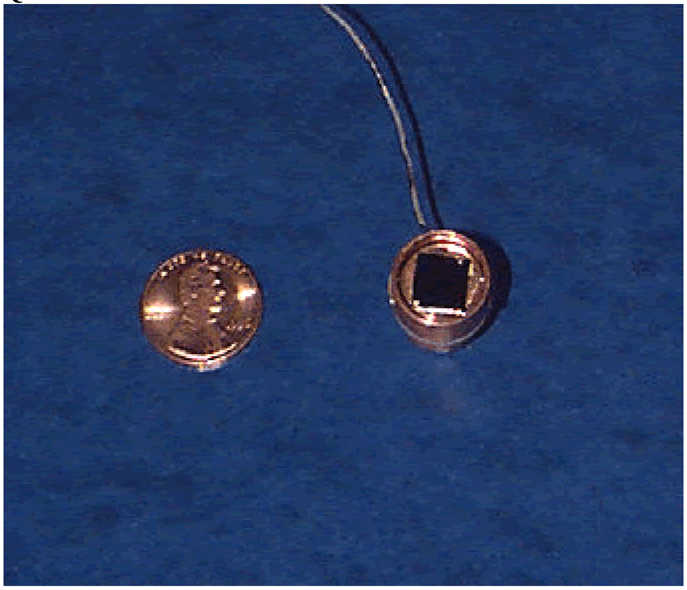
Quantum Wells Research

A study by William Loh et al found “InGaAIAs/InP quantum-well, high-power, low-noise packaged semiconductor external cavity laser (ECL) operating at 1550 nm, in which “the laser comprises a double-pass, curved-channel slab-coupled optical waveguide amplifier (SCOWA) coupled to a narrow-bandwidth (2.5 GHz) fiber Bragg grating passive cavity using a lensed-fiber. The bias was “current 4 A.”[2]

“The integration of a composite high-k gate stack (3.3 nm Al2O3-1.0 nm GaSb) with a mixed anion InAs0.8Sb0.2 quantum-well field effect transistor (QWFET). The composite gate is comprised of “stack achieves (i) EOT of 4.2 nm with 10-7A/cm2 gate leakage (ii) low Dit interface (1x1012 /cm2/eV) (iii) high drift mu of 3,900-5,060 cm2/V-s at NS of 5x1011-3x1012/cm^2. The InAs0.8Sb0.2 MOS-QWFETs with composite gate stack exhibit extrinsic (intrinsic) gm of 334 (502) micro-S/micro-meter and drive current of 380 microA/micro-meters at VDS = 0.5V for Lg=micro-meters. This research was done by A. Ali et al. [3]

Research was completed by R. A. Flynn et al found “spasing of Surface plamon polaritons at 1.46 micrometer wavelengths has been demonstrated by sandwiching a gold-film plasmonic was guide between optically pumped InGaAs quantum-well gain media.” In the demonstration showed a “gain narrowing the expected transverse-mantic polarization, and mirror feedback provided by cleaved facets in a 1-mm ling cavity fabricated with a flip-chip approach.” The 1.06 micrometer pump threshold of 60kW/cm^2 was in good agreement with the calculations. . The title of this research is A Room-Temperature Semiconductor Spaser Operating Near 1.5 um. [4][5]

Quantum Well



From: http://www.nrl.navy.mil/fpco/mrr/technology.php
Image courtesy of: Freespace Photonics Communication Office

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Qubit

Introduction

A unit of quantum information, the qubit is short for quantum bit. It is described by the quantum state in a two-state quantum-mechanical system, such as the polarization of a photon. [1]

Qubit Research

Qubits are being used in research for:

- radiation and scattering phenomenology of super wideband devices [2]
- encoding and processing information [3]

Footnotes

1. http://en.wikipedia.org/wiki/Qubit
2. Yukon, S.P., Coupled Josephson Junctions
3. Cote, Robin and Yelin, Susanne, Robust Quantum Computing Using Molecules with Switchable Dipole

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From the Research Summaries database

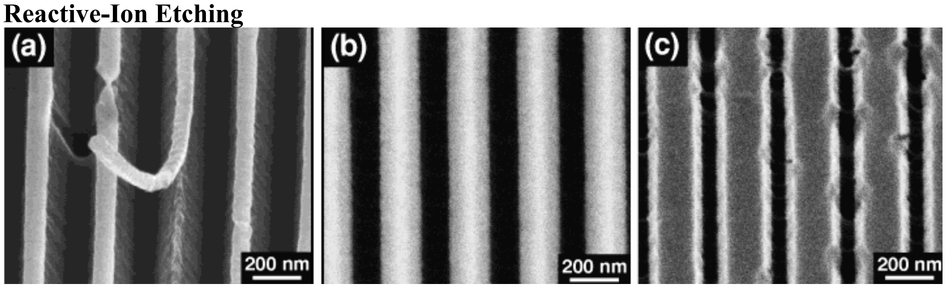
Yukon, S.P., Air Force Research Laboratory, Coupled Josephson Junctions, 12 October 2010, DF301560.

Reactive-ion etching

Introduction

"Reactive-ion etching is an etching technology used in microfabrication. It uses chemically reactive plasma to remove material deposited on wafers. The plasma is generated under low pressure (vacuum) by an electromagnetic field. High-energy ions from the plasma attack the wafer surface and react with it." [1]

Reactive-Ion Etching



From: http://physics.nist.gov/TechAct.Archive/TechAct.97/Div841/div841h.html
Image courtesy of: National Institute for Standards and Technology

Reactive-ion etching Research

Some of the most recent applications of this manufacturing process are:

- Fabrication of silicon-on-insulator (SOI) wafers for power microelectromechanical systems development. [2]
- Development of "a treatment for several forms of retinal blindness by using a retinal prosthesis, which is an implantable, microelectronic device that has been designed to interface directly with the retina." [3]

Footnotes

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3. Rizzo,J, Optimization of Microelectronic Methods To Produce An Implantable Retinal Prosthesis To Treat Blindness

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Resistivity

Introduction

"Electrical resistivity (also known as resistivity, specific electrical resistance, or volume resistivity) is a measure of how strongly a material opposes the flow of electric current. A low resistivity indicates a material that readily allows the movement of electric charge." [1]

Resistivity Research

Resistivity testing is conducted in a wide range of studies including the following:

- Development of reconfigurable surfaces for energy transmission contacts. [2]

Footnotes

1. http://en.wikipedia.org/wiki/Resistivity
2. Voevodin, A. A. et al., Nanoparticle-Wetted Relays: Reconfigurable Surfaces for Energy Transmission Contacts

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Voevodin, A. A.; Vaia, R.; Patton, S.T.; Diamanti, S.; Pender, M.; Yoonessi, M.; Brubaker, J.; Hu, J. J.; Sanders, J. H.; and Phillips, B. S., Air Force Research Laboratory, Nanoparticle-Wetted Relays: Reconfigurable Surfaces for Energy Transmission Contacts, January 2007, http://handle.dtic.mil/100.2/ADA469236.

Scanning Tunneling Microscope

Introduction

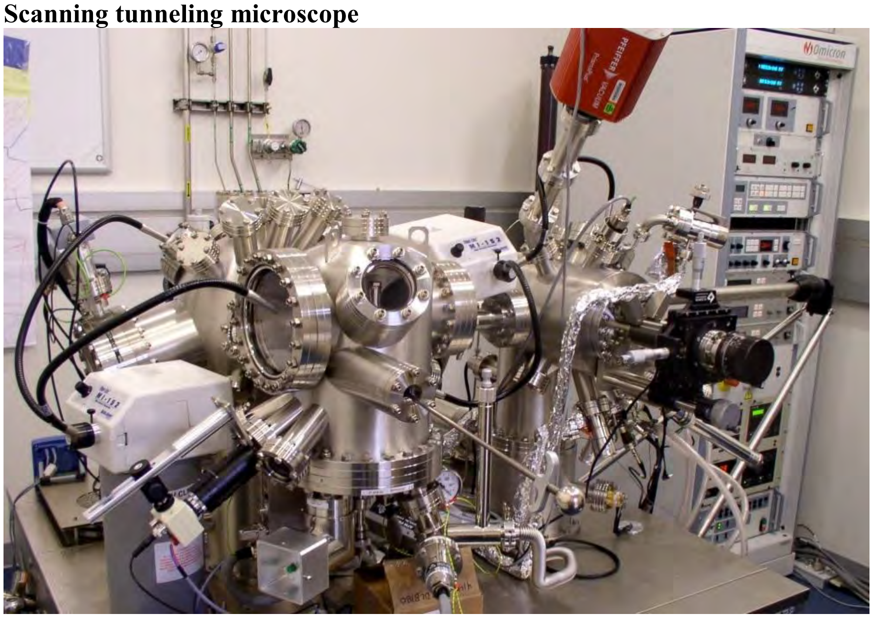
The Scanning Tunneling Microscope (STM) is “an instrument for imaging surfaces at the atomic level.” “For an STM, good resolution is considered to be 0.1 nm lateral resolution and 0.01 nm depth resolution. With this resolution, individual atoms within materials are routinely imaged and manipulated. The STM can be used not only in ultra-high vacuum but also in air, water, and various other liquid or gas ambients, and at temperatures ranging from near zero kelvin to a few hundred degrees Celsius.”[1]

Scanning Tunneling Microscope Research

Scanning Tunneling Microscopy may be applied to “understand basic mechanisms of radiation interaction” of electronic materials. One study examines the “nanostructured and thin-film fonns” of graphene, metal oxides, and diamond.[2]

The Tunneling Atomic Force Microscopy (TUNA) was used in another study to detect “electrochemical changes as mobile ions migrate along grain boundaries due to heterogeneities in grain orientation/structure” in thin film copper oxides. This study aimed at studying the “memristive properties” of these oxides, collected data from oxides of varying “chemical state[s]”. This was accomplished by “thermal oxidation” of the films which were then “deposited via magnetron sputtering onto silicon wafer substrates at an elevated temperature for various lengths of time.”[3]

Scanning tunneling microscope



From:http://nano.anl.gov/facilities/proximal_probes.html
Image courtesy of the Argonne National Laboratory

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2. Osgood, Richard et al. Physics Of Radiation Exposure And Characterization For Future Electronic Materials
3. Castle, Brett C., Memristive Properties of Thin Film Cuprous Oxide

References

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Castle, Brett C., Air Force Institute of Technology, Memristive Properties of Thin Film Cuprous Oxide, March 2011, http://handle.dtic.mil/100.2/ADA538757.

From the Research Summaries database

Osgood, Richard; EngIund, Dirk; and Kymissis, John, Columbia University, Physics Of Radiation Exposure And Characterization For Future Electronic Materials, 04May, 2011, DH057156.

Self-Assembly

Introduction

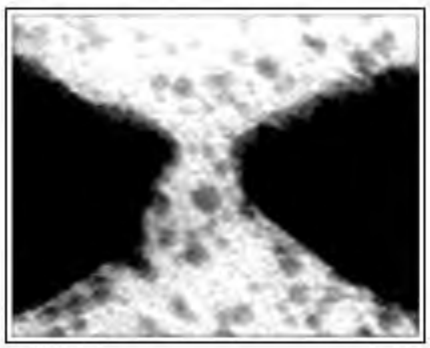
Self-assembly is the process by which a system of pre-existing components form an organized structure or pattern. Self-assembly is frequently used to describe nanotubes, among other components of nanotechnology and-or nanoscience.[1][2]

Self-Assembly Research

Self-assembling nanoparticles and other materials are being studied in research for:

- injection into a low density gel for exposure to enzymes in order to aid early breast cancer and metastasis detection [3]
- hydrolytically-stablizing drug delivery designs that can be administered aquatically [4]
- rechargeable lithium batteries [5]

Self-Assembling Molecules



From: http://www.nrl.navy.mil/estd/6870/6876/projArea5.php
Image courtesy of: Naval Research Laboratory

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1. http://www.nrsdec.natick.army.mil/media/print/Biotechnology_Trifold.pdf
2. http://www.nrl.navy.mil/nanoscience/dirselfassem.php
3. Giorgio, T., Improving Early Detection of Breast Cancer Metastases with Programmed Disassembly of Novel Nanoparticle Clusters in the Tumor Microenvironment
4. Sheihet, L., Nanospheric Chemotherapeutic and Chemoprotective Agents
5. University of Dayton, Solid-State Electrolyte for Rechargeable Lithium Batteries

References

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Giorgio, T., Vanderbilt University, Improving Early Detection of Breast Cancer Metastases with Programmed Disassembly of Novel Nanoparticle Clusters in the Tumor Microenvironment, 28 April 2011,DA373585.

Sheihet, L., Rutgers State University, Nanospheric Chemotherapeutic and Chemoprotective Agents, 09 March 2011, DA375059.

University of Dayton, Solid-State Electrolyte for Rechargeable Lithium Batteries, 04 March 2011, DF453243.

Severe Plastic Deformation

Introduction

"Severe plastic deformation (SPD) [techniques are] a generic term describing a group of metalworking techniques involving very large strains which are imposed without introducing any significant changes in the overall dimensions of the specimen or work-piece." Other feature of SPD "is that the preservation of shape is achieved due to special tool geometries which prevent the free flow of material and thereby produce a significant hydrostatic pressure." [1]

Severe Plastic Deformation

From: http://www.lanl.gov/mst/mst6/alloy.shtml
Image courtesy of: Los Alamos National Laboratory

Severe Plastic Deformation Research
The areas of research in which severe plastic deformation are used:

- Elastic-plastic finite element modeling [2]

Footnotes

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Arakere, Nagaraj K.; Branch, Nathan; Svendsen, Vaughn; and Forster, Nelson H., Air Force Research Laboratory, Stress Field Evolution in a Ball Bearing Raceway Fatigue Spall, October 2009, ADA510362, http://handle.dtic.mil/100.2/ADA510362.

Sol-gel

Introduction

Sol-gel refers to the process in which "a chemical solution (or *sol*) … acts as the precursor for an integrated network (or *gel*) of either discrete particles or network polymers." This process is "a wet-chemical technique used for the fabrication of both glassy and ceramic materials" in which the solution "evolves gradually towards the formation of a gel-like network containing both a liquid phase and a solid phase". [1]

Sol-gel Research

The sol-gel process may be applied in the treatment of open fractures. When infectious organisms infect wounds they "form antibiotic-resistant biofilm slimes". Combating infection is possible through the engineering of "a new, smart orthopaedic nail that combines antibiotic release from a biodegradable surface with the creation of a bactericidal surface on a nail" resulting in "more rapid surgical fixation of the fracture and ultimately decrease[d] disability". In this study, "sol-gel-derived silica xerogel containing vancomycin" was applied to a titanium wire using "an acid base- catalyzed process." It was found that "applying several layers of sol increased the vancomycin concentration and resulted in a timed release of the antibiotic." [2]

Footnotes

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From the Research Summaries database

Shapiro, I, Thomas Jefferson University, Orthopaedic Implants Engineered To Prevent Post-operative Infection Of Open Fractures, May 2011, DA377795.

Solubility

Introduction

"Solubility is the property of a solid, liquid, or gaseous chemical substance called *solute* to dissolve in a solid, liquid, or gaseous solvent to form a homogeneous solution of the solute in the solvent. The solubility of a substance fundamentally depends on the used solvent as well as on temperature and pressure. The extent of the solubility of a substance in a specific solvent is measured as the saturation concentration where adding more solute does not increase the concentration of the solution." [1]

Solubility Research

Solubility is an important chemical property used in different areas of Nanoscience. The following are a few examples:

- The development of "nanoparticle-based, molecular-specific approaches to breast cancer detection and treatment". One study "passivated " "nanoshells with a 119 nm silica core and a 12 nm gold shell" "with thiolated poly ethylene (PEG) to provide steric stability and solubility." It was found that "circulating nanoshells could accumulate at the tumors and give a 56% increase in OCT imaging." [2]
- A study examining "Janus Nanocrystals As A Basis For Smart Materials And Devices" was able to develop "water solubility of hybrid au-cdse nanorods using short molecules "because "use of short molecules for this purpose is necessary to still allow for accessibility of the linkers to the au tips required for using them as the anchor points for self-assembly." [3]

Footnotes

1. http://en.wikipedia.org/wiki/Solubility
2. Halas, N, Seamless Integration Of Detection And Therapy For Breast Cancer Using Targeted Engineering Nanoparticles
3. Banin, Uri, Janus Nanocrystals As A Basis For Smart Materials And Devices: Synthesis And Phase Behavior

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Banin, Uri, Hebrew University, Janus Nanocrystals As A Basis For Smart Materials And Devices: Synthesis And Phase Behavior, 13 July 2010, DF701367.

Halas, N, Rice University, Seamless Integration Of Detection And Therapy For Breast Cancer Using Targeted Engineering Nanoparticles, 15 May 2011, DA372250.

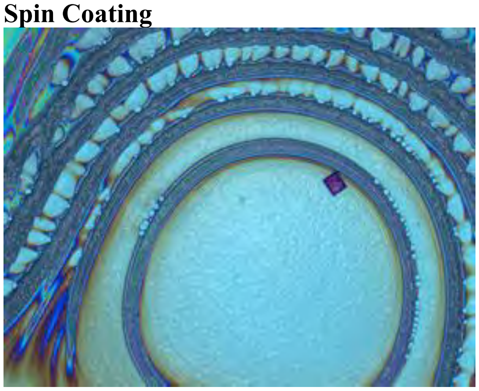
Spin Coating

Introduction

"Spin coating is a procedure used to apply uniform thin films to flat substrates….An excess amount of a solution is placed on the substrate, which is then rotated at high speed in order to spread the fluid by centrifugal force. A machine used for spin coating is called a spin coater, or simply spinner."
The process of spin coating has four distinct stages, which are:

- "Deposition of the coating fluid onto the wafer or substrate"
- "Acceleration of the substrate up to its final, desired, rotation speed"
- "Spinning of the substrate at a constant rate; fluid viscous forces dominate the fluid thinning behavior"
- "Spinning of the substrate at a constant rate; solvent evaporation dominates the coating thinning behavior" [1]

Spin Coating



From: http://nano.anl.gov/news/highlights/2010_award-winning_image.html
Image courtesy of: Argonne National Laboratory

Spin Coating Research

The areas of research that spin coating are being used:

- Ultra-Thin Polystyrene, Polypropylene and Polyethylene Films on Si Substrate [2]

Footnotes

1. http://en.wikipedia.org/wiki/Spin_coating
2. Lock, Evgeniya et al, Preparation of Ultra-Thin Polystyrene, Polypropylene and Polyethylene Films on Si Substrate Using Spin Coating Technology

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From the Technical Reports database

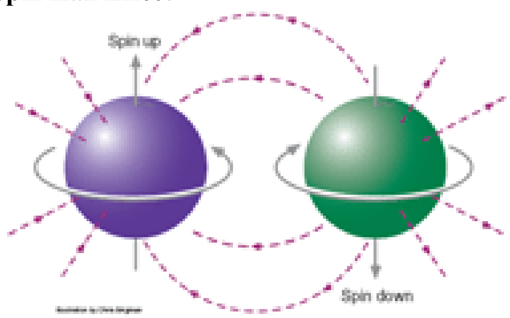
Lock, Evgeniya; Walton, Scott; and Fernsler, Richard, Naval Research Laboratory, Preparation of Ultra Thin Polystyrene, Polypropylene and Polyethylene Films on Si Substrate Using Spin Coating Technology¸, 04 January 2008 , ADA475808, http://handle.dtic.mil/100.2/ADA475808.

Spintronics

Introduction

Spintronics, or “spinning transport electronics”, strives to “exploit both the intrinsic spin of the electron and its associated magnetic moment, , in addition to its fundamental electronic charge, in solid-state devices.” Spintronics was discovered fairly recently (1980s) yet its applications have been growing exponentially as new information is being produced. [1]

Spin Hall Effect



From: http://www.lanl.gov/source/orgs/nmt/nmtdo/AQarchive/05fallwinter/page12.shtml
Image courtesy of the Los Alamos National Laboratory

Spintronics Research

One study currently in progress is looking into graphene spintronics. Three areas in particular are being investigated. These include “electron spin dynamics and transport in graphene” , “spin injection and detection via tunneling between ferromagnetic contacts and graphene”, and “specific device structures suitable for the investigation of spin phenomena in graphene and analyze the operation of these devices.” [2]

Spin Hall insulators are a recently developed method of studying spintronics. Spin hall insulators are expected to yield “intrinsic and dissipation less spin current”. These currents were employed “for spintronics application”. It was expected that the nature of the quantum spin Hall insulator is “a new sate of matter with quantized surface spin currents”. [3] In this study, the Quantum spin Hall insulator’s role as a “quantum-mechanically new state of matter where an insulating bulk supports an intrinsically metallic, spin-polarized surface state” is explored. The ultimate goal was to cultivate “new principles for spintronics devices with minimal energy dissipation, based on the fundamental understanding of those novel materials.” [4]

Another study explores the “extraordinary hall effect (EHE)” for the purposes of developing “a new type of magnetic memory devices”. The EHE enables information to be “stored in nanometric magnetic units and detection of the stored data is performed by measurement of the hall voltage across the current carrying memory unit”. The end goal of this study was the “manufacture and testing of nanoscale memory units and arrays”. [5]

Quantum Transport is an area of study in which spintronics plays a role. One study examined the “spin-dependent transport” area of quantum transport. In this study “the role of spin in nanoscopic and mesoscopic devices (spintronics),”was tested “in the context of coulomb blockade, spin injection mechanisms, quantum computing. etc.” This study also highlights the suitability of “describing transient spin dependent response in realistic devices” to Time-Dependent Density Functional Theory (TDDFT) techniques. [6]

Footnotes

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2. Ruden, Model Development For Graphene Spintronics
3. Ando, Yoichi, Exploration Of New Principles In Spintronics Based On Spin Hall Insulators

4. http://handle.dtic.mil/100.2/ADA523616
5. Gerber, Alexander, Hall Effect Spintronics
6. Verdozzi, Claudio F, New Exchange-correlation Potentials For Quantum Transport And Other Non-Equilibrium Processes As Described By Time-dependent Density Functional Theory

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Verdozzi, Claudio F., Lund University, New Exchange-correlation Potentials For Quantum Transport And Other Non-Equilibrium Processes As Described By Time-dependent Density Functional Theory, 04 November 2010, DF701446.

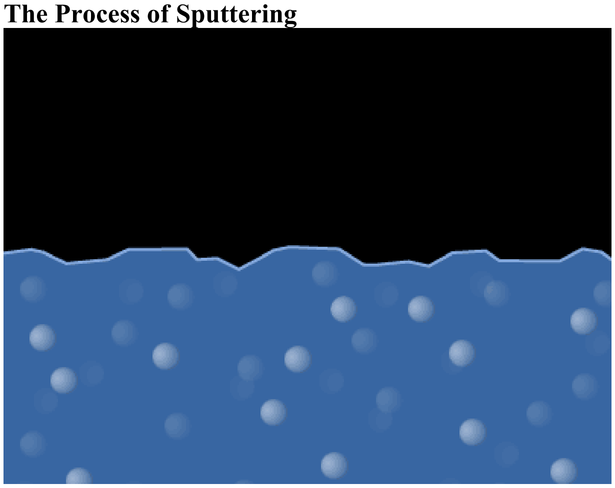
Sputtering

Introduction

“Sputtering is a process whereby atoms are ejected from a solid target material due to bombardment of the target by energetic particles.” There are many different types of sputtering.

- “**Physical Sputtering** is driven by momentum exchange between the ions and atoms in the materials, due to collisions.”
- **Heat spike Sputtering** is “a different mechanism of physical sputtering.”
- “**Preferential Sputtering** can occur at the start when a multicomponent solid target is bombarded and there is no solid state diffusion.”
- “**Electronic Sputtering** can mean either sputtering induced by energetic electrons (for example in a transmission electron microscope), or sputtering due to very high-energy or highly charged heavy ions which lose energy to the solid mostly by electronic stopping power, where the electronic excitations cause sputtering.”
- **Potential Sputtering** can be caused in “case of multiply charged projectile ions a particular form of electronic sputtering can take place.”
- **Ion milling** or **Ion etching** happens when “removing atoms by sputtering with an inert gas.” [1]

The Process of Sputtering



From: http://rosetta.jpl.nasa.gov/dsp_animations.cfm
Image courtesy of: NASA

Sputtering Research

Sputtering is being used in the following areas of research:

- "Multifunctional low-friction nanocomposite" [2]
- "Power MEMs [Microelectromechanical Systems]" [3]
- "Nano NiTi SMA fibers" [4]
- Titanium dioxide [5]
- Carbon Nanotube [6]

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5. Potrepka, Daniel M et al, Optimization of PZT Thin Film Crystalline Orientation Through Optimization of TiO2/Pt Templates
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Potrepka, Daniel M; Fox, Glen R.; and Polcawich, Ronald G., Army Research Laboratory, Optimization of PZT Thin Film Crystalline Orientation Through Optimization of TiO2/Pt Templates , January 2011, ADA536343, http://handle.dtic.mil/100.2/ADA536343.

Surface Plasmon Resonance

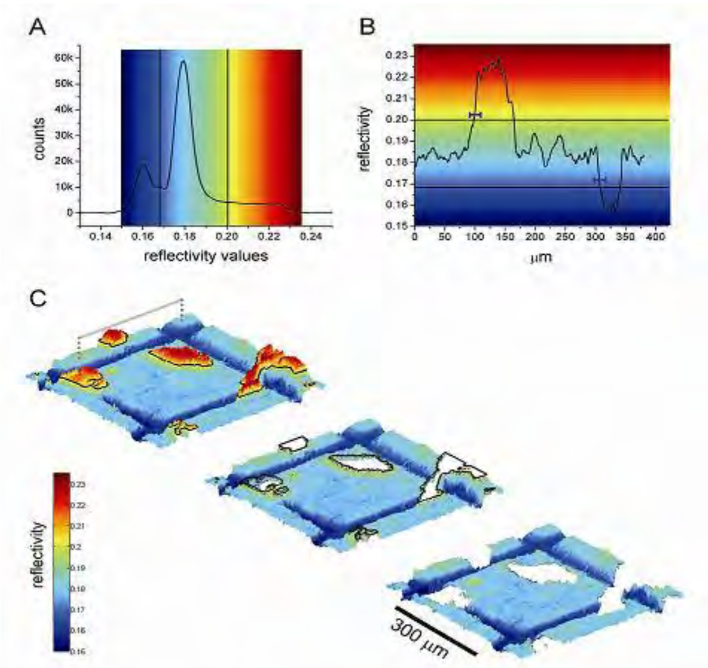
Introduction

"The excitation of surface plasmons by light is denoted as a surface plasmon resonance (SPR) for planar surfaces or localized surface plasmon resonance (LSPR) for nanometer-sized metallic structures. This phenomenon is the basis of many standard tools for measuring adsorption of material onto planar metal (typically gold and silver) surfaces or onto the surface of metal nanoparticles. It is the fundamentals behind many color based biosensor applications and different lab-on-a-chip sensors."[1]

Surface Plasmon Resonance Research

As part of a study focusing on Fcgammar And Fc (gm)genes in breast cancer, surface plasmon resonance is used as a means of measuring the "binding affinities of IgG molecules carrying different GM markers to FcgammaR molecules." "GM allotyping" was achieved through "hemagglutination-inhibition, direct DNA sequencing, and PCR-RFLP methods."[2]Surface plasmon resonance measurements proved valuable in a study investigating nanodiagnostics of cancer. The SPR measurements provided insight into "specific interaction between antibody modified nanogels and its targeted antigen bovine submaxillary mucin (BSM)."[3]

Illustration of the SPR image analysis procedure to quantify protein deposition at the periphery of smooth muscle cells



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Pandey, J., Medical University of South Carolina, Epistatic Effects Of Fcgammar And Fc (gm) Genes In Breast Cancer, 30 May 2011, DA373711.

Thermophoresis

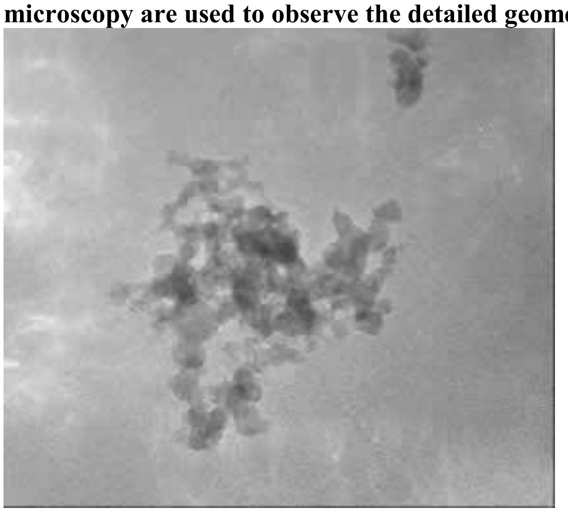
Introduction

Thermophoresis, a "phenomenon [which] is observed at the scale of one millimeter or less", occurs "when a mixture of two or more types of motile particles (particles able to move) is subjected to the force of a temperature gradient and the different types of particles respond to it differently."1[135]

Research

In order to investigate the "transport and interfacial phenomena in multiphase combustion systems", two "thermophoresis-based methods for measuring absolute local soot volume fractions, fv, in flames were successfully implemented in both co-flow and counterflow laminar diffusion flames." These two methods, particle densitometry (tpd) and thermophoretic sampling particle diagnostic (tspd), "were independent of (often unknown) soot optical properties, unbiased with respect to soot morphology and size distribution, and yielded spatially resolved fv values directly even at low soot concentrations (below 0.1 ppm)."[135]

A unique combination of thermophoretic sampling techniques and high-resolution transmission electron microscopy are used to observe the detailed geometry of diesel particulates.



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http://www.anl.gov/Media_Center/News/2004/news040416.htm

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References

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Transparent Armor

Introduction

“A multi-hit transparent armor system is described for improving the resistance of transparent armor to incoming projectiles. Typically, the transparent armor is framed within a window opening of a security structure. An exemplary, contemplated structure is an armored combat vehicle." [1]

Transparent Armor Research

Researchers at the Army Research Development Engineering Command are working on developing “nano-structured ceramic bodies with a combination of high optical transmission and exceptional mechanical properties and capable of effective performance in an outstanding transparent armor system.” [2]

The Army Research Development Engineering Command notes that there has been an “exponential increase in demand for M1114 windshield glass and door window glass from 2004 to 2006.” Armor solutions are being developed “which have a timeline out to 2010; two funding efforts to develop nano-structured ceramic bodies with high optical transmission and exceptional mechanical properties; the purpose of the government's cost-benefit study and current expenditures for windshields and door windows; the study methodology that will be used to find a break-even cost – parametric analysis; and timeframe for the research study.” [3]

Transparent Armor

“WRIGHT-PATTERSON AIR FORCE BASE, Ohio – This ground-finish transparent armor test piece withstood the impact of a .30 caliber armor-piercing bullet fired from 25 yards away using a Russian M-44 sniper rifle. Shown is the test piece, which demonstrates the armor's ability to stop penetration from armor-piercing threats. (U.S. Air Force photo)”

From: http://www.afmc.af.mil/news/story.asp?id=123012242

Image courtesy of: Air Force Materiel Command

A transparent armor system purposed by the Tacom Research Development And Engineering Center "includes a sheet of tempered glass that is also positioned within said window, but is deployed outboard of said transparent armor and is also parallel planar thereto. Positioned below said sheet of tempered glass, and coaxial thereto, is an opaque armor panel that is more efficient and effective against multiple projectiles than either the tempered glass or transparent armor alone. The tempered glass sheet and the opaque armor are typically loaded under compression by a spring assembly. An incoming projectile, launched from a position outboard and also remote from said structure, will first strike the tempered glass before hitting my transparent armor. Thereby, the tempered glass sheet will undergo global failure and is effectively removed from the window opening. In turn, the spring assembly translates the opaque armor into the position formerly occupied by the tempered glass sheet. Subsequently arriving projectiles are then defeated by the opaque armor panel.” [1]

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